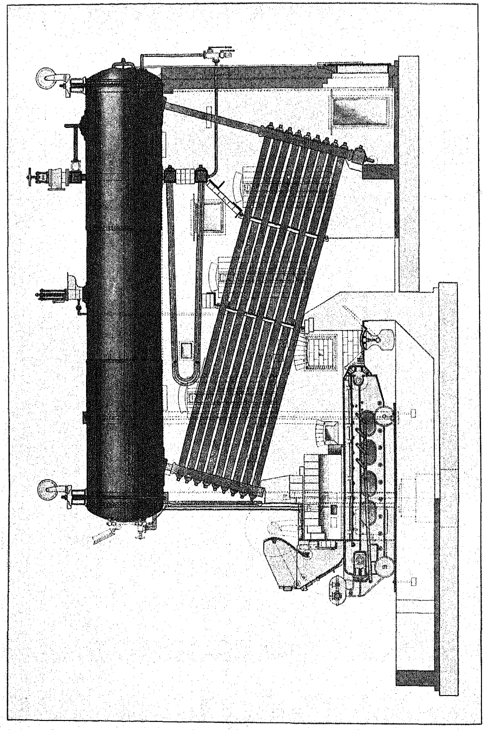

SCIENCE
IN · MODERN · LIFE

A SURVEY OF SCIENTIFIC DEVELOPMENT DISCOVERY AND INVENTION AND THEIR RELATIONS TO HUMAN PROGRESS AND INDUSTRY

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VOLUME VI

ENGINEERING

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ENGINEERING

CHAPTER I

INTRODUCTORY—SOURCES OF ENERGY—WATER POWER—AIR POWER

INTRODUCTORY

THE MODERN ENGINEER.—As the conditions of civilized life become ever more complex, the engineer is of necessity compelled to devise newer and more efficient means whereby the available forces of nature may be applied in the service of mankind. Each improvement effected in any branch of engineering serves as a foundation for extensions in other and widely different directions, and it is this essential element of interdependence that compels the engineer to acquire a comprehensive knowledge of every branch of his profession, so that he may be able to profit in his own special work by the advances of others. But in addition to the work of devising and constructing, the engineer is often called upon to fulfil the important administrative duties involved in the control of large bodies of workers, upon whose efficiency the economic production of the work depends.

For the execution of his more professional duties the engineer should have a clear understanding of the properties of matter and of the laws that govern them, not only in the qualitative, but more particularly in the quantitative aspect; and, above all, he should possess such actual experience as will enable him, when considering any engineering problem, to determine what principles are involved and what is their relative importance. Between practice and theory correctly exercised there can be no real conflict, and it is the difficulty of appreciating the determining factors of the question under consideration that most often leads to an apparent disagreement.

ENGINEERING AND SCIENCE.—Although the practice of engineering is dependent upon the advance of pure science, it is fortunate that there can be progress notwithstanding the incomplete state of our knowledge regarding the fundamental constitution of matter or the nature of gravitation and its relationship to other natural phenomena. It is, however, certain that the satisfactory elucidation of these problems would result in a greatly increased rate of progress, and it is equally probable that in

many respects the practice of to-day would undergo a revolutionary change. It is not essential that the smith should know what are the molecular forces that determine the properties of the iron he has to forge; it is sufficient that he should know the temperature at which it may best be worked, and be aware that above a certain temperature the molecular arrangement of the material will undergo changes rendering it unsuitable for his purpose. A dwelling may be made to serve all the purposes for which it was designed without necessitating on the part of the owner any precise knowledge of the foundations, provided they are sound. In the same way, notwithstanding his incomplete knowledge of the foundations of nature, the engineer who is familiar with the behaviour of his materials under the various conditions that arise in practice can prophesy with some certainty the result of any series of operations he may wish to execute.

NEW CONDITIONS.—As the general store of experience and data increases, and as the number of professional workers grows larger, it might be thought that the work of the engineer would be lightened; but in reality, as the boundaries of progress are enlarged, the difficulties to be surmounted increase both in number and complexity, and the requirements to be satisfied become continually more severe.

Under the present competitive conditions the closest study of every detail is essential to the maintenance of any position in the manufacturing world, and it is this competitive rivalry between nations and between individuals that has determined much of the progress of engineering. One striking example of the rivalry that exists to some extent in every sphere, is the continuous struggle for supremacy between gas and electricity. On the introduction of electric light it was thought by many that gas for lighting purposes would be largely superseded; but in reality, although electric light is extensively employed, the consumption of gas for the same purpose has increased to a still greater extent. The development of the incandescent mantle has resulted in the readoption of gas for street lighting, but the still more recent improvements effected in the design of metallic-filament lamps have again brought the electric lamp more nearly abreast of its rivals.

SOURCES OF ENERGY

In the following pages the various systems of power production will first be described, and thereafter the more important applications of power thus developed will be discussed. Before dealing, however, with these applications the manufacture and properties of the chief materials of construction will be briefly considered.

The natural sources of energy are distributed in one condition or another over the whole world, but the practical value of the source is determined by the nature and continuity of the supply and by the ease with which it may be transformed to a convenient and concentrated form. Of the present available sources the most important are the fuels, coal and oil, and water; but there are other and greater stores of molecular energy which as yet are in the hands of the physicist and far beyond the reach of

the engineer who would employ them. Water is widely distributed over the world at suitable heights above the sea level, but unfortunately this very direct form of power can only be utilized in the comparatively near neighbourhood of the source, whereas in the case of coal and oil the fuel may be transported to distant regions where suitable supplies do not exist. In certain regions of the world, such as California, where the quantity and strength of the sunlight are considerable, the direct heat of the sun is sometimes utilized to a small extent by concentrating the rays upon a water boiler placed in the focus of a large parabolic mirror. SUN MOTORS of this description are, however, impracticable in other countries where the sunlight is intermittent and less intense.

When COAL is burned upon the grate of a steam boiler a portion of the heat developed is transmitted through the plates to the water, which is converted into steam at a pressure depending upon the temperature attained; but a considerable part, amounting in an average case to one-third of the heat, is lost through incomplete combustion and also by the escape of the hot gases through the chimney to the atmosphere. Of the heat that enters the water a large proportion is absorbed in changing the state of the water, and as this heat is not utilized in the working cylinder the combined efficiency of the engine and boiler is greatly reduced. Attempts have been made to burn finely pulverized coal more directly in the cylinder of an engine, but owing to the mechanical difficulties involved no satisfactory results have so far been obtained. By distilling the coal and burning the gases produced in the cylinder of the engine the necessity of producing steam is avoided, and internal-combustion engines which consume not only gas but also oil and oil vapours are now very extensively employed, especially for small powers.

MANUAL LABOUR of an unskilled kind is still an important source of power for certain kinds of work, and if the total energy thus expended could be estimated it would doubtless prove to be enormous. Such labour, however, cannot be centralized, as it must be for the driving of machinery, and the cost of manual labour as ordinarily applied is for many industrial purposes prohibitive. Wherever labour is dear it will be found that it has been supplanted, so far as the actual labour is concerned, by special machinery, and that in such countries the development of engineering has been very rapid. Skilled labour cannot be considered as a source of power, since in such cases it is the craftsmanship that is of value.

ANIMAL LABOUR plays a still more important part in the work of the world; but even in this form the energy available is not sufficiently concentrated, and in many departments of engineering, such, for example, as traction, the horse is being generally abandoned in favour of more convenient engines of greater power.

WATER POWER

Of the many natural forms of energy, water power lends itself most readily to industrial purposes; and where it exists in suitable quantities it is applied with very economical results to the driving of machinery, or to

the production of electricity, which may then be distributed to other districts where water power is not available. Although there are innumerable small sources throughout the various countries, it is unfortunate that the number of localities favoured with important supplies is not great, and in many of these cases it is remarkable that they are far removed from any large industrial centre. In the case of Niagara the water power is transformed into electrical energy and transmitted as far as Buffalo, where it is utilized in the factories; but the cost of transmission is considerable, and the area of distribution is thus limited. Many new factories have been transferred to the Niagara district itself; but this solution of the difficulty is not always possible, since the situation of a factory is determined largely by the facilities for the transport of the raw materials and of the finished goods.

Tidal Energy.—Before proceeding to discuss the methods of transforming the energy stored in water it will be of interest to consider quantitatively the energy obtainable from the tides. In practice, where the height of the tide is considerable, the water might be allowed to flow into a large reservoir as the tide rose, and then during the ebb the energy of the falling water might be utilized by means of water wheels or turbines or other suitable machines. It is possible that a certain amount of the energy of the flowing tide might be transformed, but this amount is neglected in the following estimate, and the whole of the energy in the ebbing tide is considered as being obtainable. The energy expended in the fall expressed in foot-pound units will be equal to the weight (in pounds) of the water multiplied by the mean height (in feet) of the fall. Thus, if the fall of the tide be 2 ft., the mean fall, that is, the height through which the centre of gravity of the body of water falls, will only be 1 ft. By calculation it appears that from each acre of reservoir 160 h.p. would be the maximum obtainable during one minute for a tidal rise of 2 ft. If the rise were as great as 10 ft., the power obtainable for one minute per acre would be only 4000 h.p. Considering the increasing value of land, and the cost of the installation of such a system, any extensive utilization of the tides does not appear to be feasible under existing conditions. It would be possible at the present day to install upon the same area, one acre, a steam plant which would continuously develop from 15,000 to 20,000 h.p.

Tidal energy may be successfully utilized for very small powers when the rise is considerable and the conditions are favourable, as, for example, on the Bristol Channel, where the ebb and flow of the tide has in one small plant been made to drive a water wheel. Such examples are not, however, numerous or of much industrial importance.

Potential and Kinetic Energy in Water.—Whereas the energy of the tides is obtained from the moon, and to a smaller extent from the sun, the water power which can be applied most readily to the driving of machinery is indirectly derived from the sun alone. During the heat of the day the water of the sea and of the lakes and rivers evaporates under the action of the sun, and the vapour is absorbed by the heated air. At night, when the temperature of the air falls, the vapour is de-

posited as dew upon the ground, and this is especially the case on the higher portions where the temperature varies most. Sudden variations of temperature may result in the condensation of the moisture as rain or snow, but a very considerable proportion of the water deposited on the mountain tops is due to the regular nightly fall of dew. A portion of the deposited water gravitates to the sea level as surface streams and rivers, and a second portion sinks downwards into the earth until stopped by an impervious stratum of rock or clay. In the basins and fissures formed by such strata the water accumulates and forms the sources of the springs which flow with great constancy, in the case of the deeper-seated ones, however irregular the rainfall may be. When water is stored at a height above the sea it constitutes a source of power, the total amount being determined by the weight of the water thus stored and by the vertical height through which it must fall before it reaches the sea level, which forms the datum line in the estimation of all water power. If the stored water is at rest its energy is said to be in a potential or pressure form, and if it is flowing, a portion of the energy appears in a kinetic form. According to the principle of the conservation of energy, which is applicable under all conditions, the energy stored in the water must be the same whether it is in the pressure or the kinetic form, or in both combined; that is to say, any increase in the energy of motion of the falling water must be accompanied by a corresponding decrease of the pressure energy.

If the energy is in the potential form, some type of pressure engine or turbine may be adopted for the utilization of the power, and, on the other hand, if the energy is kinetic, some other type, such as the impulse turbine, will be required. Sometimes, as already stated, the energy exists in both the potential and kinetic forms, and a third type of motor, combining the essential features of the two kinds above mentioned, may be employed.

WATER RAMS.—In a running stream the water possesses kinetic energy which may be utilized to raise a portion of the water to a height greatly exceeding the actual fall of the stream itself. If the height to which it is required to raise the water be great, the quantity will be correspondingly less, as the power available is determined by the strength of the stream. The water ram invented by M. Montgolfier is a simple apparatus long used for this purpose. At the present day these water rams are extensively used for agricultural purposes and for supplying water to highly situated private houses. A typical example, made by Glenfield & Kennedy, of Kilmarnock, is illustrated in fig. 465. Across the supply stream is built a small dam, from the base of which a pipe is led and connected to the ram at D P, and from R P is led the rising pipe through which the water is to be pumped. D V is a valve which, owing to its weight, always tends to open downwards, and C V is a non-return valve which allows water under pressure to pass upwards but prevents its return. As the water flows from the reservoir into the ram it escapes through the open valve D V and passes away to waste. The opening of the valve is, however, not sufficiently large to pass all the water, and the flow is

accordingly throttled, with a consequent diminution of the velocity energy, and a corresponding increase of the pressure. When the pressure rises sufficiently to raise and close the valve D V the motion of the stream is arrested, and the pressure rises suddenly to an extent limited only by the energy of the stream. Under this pressure the water passes through the non-return valve into the pipe attached at R P. As the water thus commences to flow again, the pressure decreases until, at a certain point,

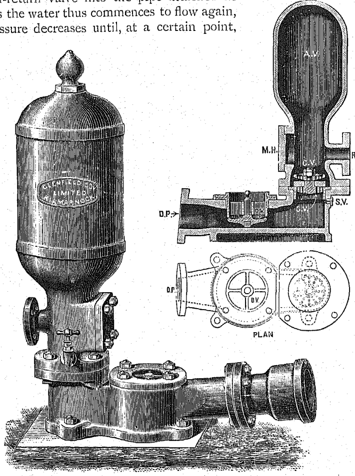

Fig. 465.—Hydraulic Ram

the valve D V opens under its own weight, which is carefully adjusted to suit the particular conditions, and the water escapes as before through the valve to waste. This cycle repeats itself automatically, and the water rises upwards in the pipe by intermittent stages. It is understood that the invention was suggested to Montgolfier by the loud hammering which occurs in a vertical water pipe when a tap at the lower end is quickly closed. Screw-down taps are invariably used on domestic supply pipes, to prevent rupture caused by the sudden rise of pressure which occurs when the motion of the water is suddenly stopped. To secure regularity of

the action, and to prevent the pressure from rising too suddenly and violently, it is necessary to add an air vessel A V. When the pressure is high the air is compressed, and as the pressure falls the air expands and maintains for a longer period a more regular flow of water in the rising pipe R P. In practice it was found that the air in the vessel A V was absorbed by the water, which then completely filled the chamber and stopped the action. To remedy this defect a small snifting valve, so arranged as only to open inwards against the action of a spring, was added, as shown at S V. At each pulsation air is drawn in through the valve, and passes with the water into the air vessel to compensate the loss through absorption. It will be evident that the efficiency of the apparatus cannot be great, but for the purposes already mentioned great efficiency is not of first importance. Only about 5 or 6 per cent of the water is actually raised, but as the pulsations may be over 50 per minute and the action continues both day and night, the quantity of water delivered may be considerable.

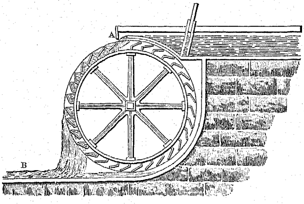

Fig. 466.—Overshot Water Wheel

WATER WHEELS.—Water wheels of the primitive type in use 200 years before the Christian era may be seen working at the present day, but they are being entirely superseded by the more efficient and convenient water turbine. In its earliest form the water wheel consisted of a number of broad float-boards arranged radially around the periphery of the wheel, with the lower ones immersed in the running water, which drove them forward. On the same axle, or in gear with the periphery, was arranged a large toothed wheel, from which were driven the millstones or other machinery. A later improvement consisted in slightly inclining the floatboards in the direction of the stream, so as better to retain the water. Wheels of this kind utilize the kinetic energy of the water, and are known now as IMPULSE WHEELS, to distinguish them from PRESSURE WHEELS, which derive their motion from the weight of the water above them.

UNDERSHOT WHEELS, which are driven by the action of the water flowing under them, were at one time greatly favoured on account of their simplicity and the ease with which they could be installed on streams of small fall; but, so far as efficiency is concerned, the performance of such wheels is not good. In wheels of the overshot and breast types, both the weight and the impulse of the water are utilized, and the performance of the wheel is thus much improved. An early example of an OVERSHOT WHEEL is shown in fig. 466, from which it will be seen

that the water is led to the top of the wheel and discharged at the bottom the available head of water being the height between the penstock level A and the level of the tail-race B; but actually the head is considerably less, as the water is discharged before the buckets reach the bottom. As already mentioned, the water acts over a portion only of the effective circumference of the wheel. With a view to remedying this defect the BREAST WHEEL was introduced, but the superiority of the arrangement is doubtful, owing to the difficulty of preventing leakage. In the breast wheel the mouths of the buckets generally open in the opposite direction to those of the overshot wheel, and the water is carried by the other side —that is, in the space between the wheel and the breast wall.

PELTON WHEEL.—An undershot wheel having straight float-boards is a much less efficient machine than the overshot wheel driven solely

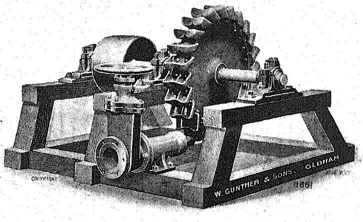

Fig. 467.—Pelton Wheel (casing removed)

by the weight of the falling water. In the case of the latter the water is discharged at the lower level from the buckets in a more or less spent condition, and with buckets well ventilated to prevent the splashing that otherwise takes place, due to the accumulation of air, an efficiency of about 70 per cent is obtainable. In the case of the impulse wheel with flat floats the maximum theoretical efficiency is only 50 per cent, and the actual efficiency is very much less. This will be evident when it is considered that the water is discharged with a velocity equal to that of the wheel floats. It is theoretically possible, by suitably forming the buckets, to abstract the whole of the kinetic energy of the water, and thus obtain an efficiency of 100 per cent. In the early Poncelet undershot wheel the floats were so curved that the water at the moment of discharge flowed from them in a direction opposite to that of the stream with a considerable velocity, but the same idea is better illustrated in the Pelton wheel, fig. 467, which was first introduced in America. Around the periphery of the wheel are arranged double buckets, which rotate in turn past the nozzle of the water-supply pipe, shown in position in the illustration. The water issues from the nozzle with a velocity deter-

mined by the head of water, and impinges upon the buckets, which are so curved as to deflect the water to either side, and backwards in a direction parallel to its original course. If the velocity of the buckets is about half the velocity of the jet, the water will be discharged with no velocity relatively to the earth, and therefore all its available energy will have been abstracted by the wheel, one half of the energy being expended in the impact and the other half in the reaction of the water while being deflected backwards. In practice the jet of water is not completely turned through 180 degrees, but is discharged towards both sides with a velocity sufficient to carry it clear of the wheel. When properly designed, and when working under normal conditions, an efficiency of over 80 per cent is obtainable, but there is some difficulty in efficiently regulating the Pelton wheel when the supply of water varies to any great extent.

For the driving of dynamos, and in other cases where the demands for power vary considerably, it is necessary to use a centrifugal governor for automatically regulating the speed even at the cost of efficiency. Instead of opening and closing the water-supply valve, which could not be done with sufficient rapidity, the governor acts upon the nozzle and deflects it slightly to one side about a pivot, so that the jet partly misses the wheel. In another type the halves of the buckets are carried upon two wheels arranged side by side upon the same axle. As the speed rises the governor separates the wheels, and thus allows a portion of the jet to pass idly between the halves of the buckets.

WATER MOVEMENT IN PIPES.—Before describing the different kinds of turbines, the action of which depends upon the motion of the water through curved passages, it will be advisable to consider the changes that take place as water passes through a pipe of varying section. If the pipe be completely filled, the velocity of the water will vary inversely as the sectional area, since the quantity which passes any section per unit of time must be the same throughout. At the narrow portions the velocity will be great, and at the larger-diameter sections correspondingly less; but, as already explained, a reduction of velocity must be accompanied by a rise of pressure if the total energy remains unchanged, and therefore at the small sections the pressure will be low and the velocity high, while at the large sections the pressure will be high and the velocity low. By varying the form of the passages, or as they are called in turbine practice "vanes", the velocity and pressure of the water may be relatively altered as desired.

WATER TURBINES.—From an historical point of view the SIMPLE REACTION WHEEL illustrated in fig. 468 is of some interest as being the early form from which have been developed the turbines of the present day. It was invented in the seventeenth century by Dr. Barker, who called it a centrifugal mill; but, as will be shown later, centrifugal force plays a less important part than reaction. The tube U, supported upon a pivot at W, and guided at the top, is provided with two hollow arms, each of which has a water exit, as shown at A and Z. Water admitted to the tube U through the funnel V passes along the arms and escapes tangentially and in opposite directions from the apertures. If the apertures did not exist,

every portion of the tubular arms would be acted on by the water pressure due to the head of water in the vertical pipe U; but when the apertures are opened the pressure over these areas no longer exists. On the portions of the tubes opposite the apertures the pressure still remains, and, being unbalanced, drives the arms round in a direction contrary to that of the escaping water. The motion is therefore due to reaction, and hence the term *reaction wheel*. Centrifugal force has also some influence, because as the arms revolve the centrifugal force of the contained water increases the effective head, and by measuring the water discharged in a given time it can be shown that the quantity is greater when the wheel is revolving than when held stationary.

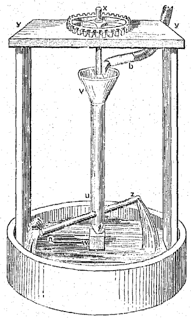

Fig. 468.—Barker's Centrifugal Mill or Reaction Wheel

In principle the pure reaction wheel is defective, because the water is discharged with a considerable velocity relatively to the earth, which means so much lost energy. In modern turbines an initial rotational velocity or whirl is communicated to the water, so that when it leaves the turbine-wheel vanes its velocity relatively to the earth is such that it just moves clear of the wheel and its whole available energy is thus abstracted.

It is customary to classify turbines according to the general course of the water through the wheel in relation to the axis of rotation. Thus the terms OUTWARD FLOW, INWARD FLOW, and PARALLEL FLOW are commonly used to distinguish those turbines in which the water flows radially from the axis, or radially towards it, or in a direction parallel to it. Sometimes the course of the water is both radial and parallel, in which case the term MIXED FLOW is used. Another and more scientific classification is based upon the condition of the water as it passes through the wheel, and this is the classification that will be adopted here, namely, PRESSURE OR REACTION TURBINES and IMPULSE TURBINES. To the first group belong the Fourneyron, Jonval, and Thomson turbines, and to the second the Girard turbine and the Pelton wheel.

A turbine usually consists of two rings of curved vanes or buckets arranged concentrically or one above the other. One set of buckets is fixed and serves to change the direction of the flow, so that the water will enter the second set of moving vanes with the desired motion and without shock. In turbines of the pressure type the buckets must be kept full of water, owing to the pressure which exists throughout, and since there is a pressure in the clearance space between the wheels they must be run as closely together as possible to avoid loss of water. To obtain the maximum efficiency the water must be admitted to all the

buckets simultaneously, as otherwise there will be considerable loss in either expelling dead water or in wastefully filling the empty passages. The necessity for full admission makes the efficient regulation of pressure turbines a matter of considerable difficulty, and in practice the system generally adopted is to partially reduce the admission by means of gates at the entrances to the guide buckets, although the efficiency is thereby considerably affected. At full gate the efficiency of an ordinary outward-flow turbine may be about 75 per cent, while at quarter gate the efficiency will probably fall to 25 per cent. Pressure turbines may be run completely immersed, as shown in fig. 469, which is an example of a Jonval

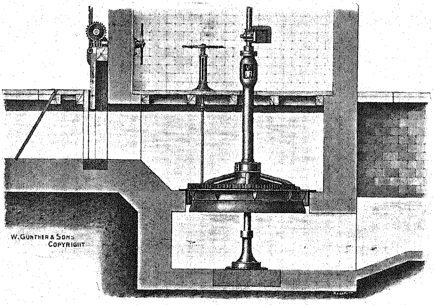

Fig. 469.—Jonval Reaction Turbine

turbine plant installed by Messrs. Gunther & Sons. When desired, however, the wheel may be raised above the tail-water level, and in such cases the discharge pipe is made to dip under the surface in order to utilize the suction of the remainder of the fall. A pressure turbine is best suited for low or medium falls where the tail-water level fluctuates.

The late Professor James Thomson, of Glasgow University, effected a great improvement in the economy and regulation of pressure turbines by the introduction of the DOUBLE-VORTEX arrangement illustrated in fig. 470. The water flows inwards through the long curved guides shown, and enters the moving wheel, from the centre of which it is discharged. By discharging the water at the slowest moving part of the wheel it is possible to eject the water with the least velocity.

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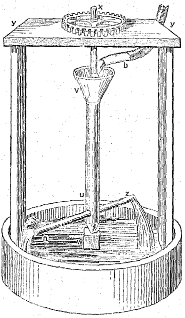

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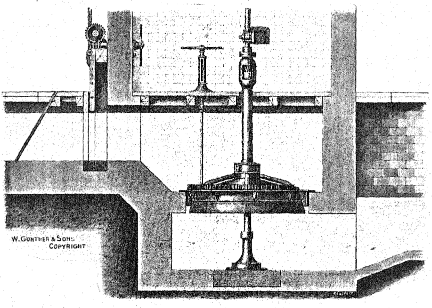


Fig. 469.—Jonval Reaction Turbine

turbine plant installed by Messrs. Gunther & Sons. When desired, however, the wheel may be raised above the tail-water level, and in such cases the discharge pipe is made to dip under the surface in order to utilize the suction of the remainder of the fall. A pressure turbine is best suited for low or medium falls where the tail-water level fluctuates.

The late Professor James Thomson, of Glasgow University, effected a great improvement in the economy and regulation of pressure turbines by the introduction of the DOUBLE-VORTEX arrangement illustrated in fig. 470. The water flows inwards through the long curved guides shown, and enters the moving wheel, from the centre of which it is discharged. By discharging the water at the slowest moving part of the wheel it is possible to eject the water with the least velocity.

Centrifugal force also plays an important part in the action, especially in balancing a portion of the pressure. As the wheel rotates, the centrifugal

action of the contained water increases the pressure at the circumference, and so reduces the difference of pressure which exists between the exit from the guides and the entrance to the buckets. Wherever a sudden difference of pressure occurs in the flow of water there is a considerable loss of energy due to shock and the formation of eddy currents, and this is largely obviated in the vortex turbine, as just explained, and also by the unusual length and the form of the guide vanes. Owing also to the centrif-

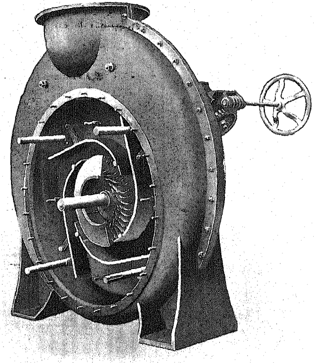


Fig. 470.—The Double-vortex Reaction Turbine of Professor James Thomson (discharge pipe removed)

ugal action the speed regulates itself automatically as the load varies. If the load be suddenly reduced the speed of the wheel increases, and with it the centrifugal pressure of the water which retards the flow from the guide vanes. Similarly, when the speed falls, owing to an increase of load, the pressure at the circumference of the moving wheel falls, and a larger supply of water is admitted. Outward-flow turbines act in the reverse way and accentuate any fluctuations of the speed, while in the parallel-flow types the centrifugal action has no effect.

When the supply of water varies, the guide vanes are rotated about their inner pivoted ends so as to alter the sections of the guide passages without introducing sharp obstructions. The illustration of the Thomson vortex turbine (fig. 470), manufactured by Gilbert Gilkes & Co., of Kendal,

shows clearly the adjustable guide vanes and the wheel contained in the supply casing from which the discharge pipe has been removed.

Impulse turbines are used for high falls, since it is possible to work them with partial admission, and they do not run submerged. With a high fall the water friction and eddy losses would be considerable in the case of a quickly moving submerged wheel, and as partial admission is not economically practicable the wheel diameter and the speed of rotation would require to be inconveniently great. For high falls exceeding 100 ft. the unsubmerged impulse turbine is therefore adopted, as it runs equally well with partial admission. In its passage through the guide vanes the whole available energy is transformed into the kinetic form, and the pressure is thus reduced to that of the atmosphere. When the water enters the wheel it glides along the surfaces of the vanes without filling the buckets, and imparts its energy to the wheel. At all parts of the wheel the pressure is merely that of the atmosphere, but to ensure the absence of lower pressures, which might cause splashing, the buckets in the Girard turbine are ventilated to prevent the water from leaving the surface.

AIR POWER

WINDMILLS.—For industrial purposes the force of the wind is of too intermittent and indefinite a nature to make its extensive adoption possible in competition with other sources of power, such as water and fuel, when these are readily obtainable. At sea the currents of air are not so indefinite, and on certain trade routes a large part of the merchant traffic is carried on by means of sailing ships. As an auxiliary to the steam engine at sea the wind sail is a very valuable addition, and it is largely taken advantage of.

Windmills are most generally employed for the pumping of water, the grinding of grain, and other agricultural purposes; but their use is more or less limited to certain situations where the winds are constant. There are certain places near the sea where the wind blows with great regularity from the sea during the daytime and from the land during the night, and in these places windmills are frequently used for driving grain mills and for similar minor purposes. Although windmills are known to date from an early period, it is very doubtful where and how they actually originated. It is certain, however, that many of them were employed in the twelfth century, particularly in Holland, for pumping water through the low-lying canals.

EUROPEAN WINDMILLS represent the more ancient types of wheels, which generally consist of four arms upon which the sails are spread, while the modern development is represented by the AMERICAN MILLS, which have continuous wheels composed of numerous narrow blades or slats. So far as Continental mills are concerned, there are two kinds, which differ in the method adopted of bringing the wheel into the wind. In the DUTCH WHEEL the walls of the tower remain stationary, and only the roof or head carrying the wheel and shaft requires to be turned to suit the direction of the wind. GERMAN OR POST MILLS, on the other hand, are carried upon a central vertical shaft, and the whole mill is turned either by

hand or mechanically. Between these two extreme types there are others in which a portion of the mill is pivoted, but the simple Dutch and German constructions are most commonly to be seen on the Continent.

Some makers prefer flat sails, inclined to the surface of the wheel at various angles dictated chiefly by their experience, while others advocate curved vanes. Each system doubtless possesses certain features of advantage, and it is difficult to make any very definite comparison of their respective merits. To utilize the wind to the greatest advantage it is essential to provide means, either manual or automatic, for turning the wheel as the direction changes, and for governing the motion as the force varies. The automatic arrangement for directing the wheel usually consists in a small secondary wheel placed at right angles to the main one, so that, when the direction of the wind alters, the little wheel is acted upon, and by means of suitable gearing the large wheel is rotated until it once more faces the wind. American wheels are much more lightly built of steel and wood, and can be easily controlled, so far as direction is concerned, by means of a flat balance vane placed, in some cases, at right angles to the wheel and in line with the wheel spindle.

To regulate the speed as the force of the wind varies, many ingenious arrangements have been devised, and there is now little difficulty in maintaining a speed sufficiently constant for all practical purposes. In the earliest mills a brake was fitted on the wheel shaft, but this arrangement was soon abandoned in favour of the system of reducing the area of sail presented to the wind. The sails were so arranged in the early mills that they could be rolled up or furled as required, but this involved frequent stoppages, as the furling was done by hand. In 1780 Andrew Meikle attached the sails in sections to transverse rollers, and fitted a centrifugal governor which automatically rolled up the sails and thus reduced the exposed area in proportion to the increase of speed. Suitable weights were provided for unfurling the sails again as soon as the speed was reduced to the desired limit. In another type, devised by Sir William Cubitt in 1860, the sail was divided into sections pivoted in such a way that the wind could pass idly through the wheel when they were opened by the action of the governor. This system of opening or closing the blades is the one frequently adopted in American wheels of the present day.

There are two general classes of AMERICAN WINDMILLS, distinguished principally by the methods adopted for governing the speed. In the SECTIONAL-WHEEL ARRANGEMENT, the pivoted slats of the wheel are turned more or less with their edges to the wind by the action of centrifugal governors, and in the SOLID-WHEEL TYPE the slats are fixed, and the whole wheel is turned out of the wind, which acts upon side vanes. In each case independent rudders are provided to bring the wheel into the wind; but in one type of American wheel, the Leffel, first introduced in 1880, the independent rudder serves the double purpose of regulating the speed as well as the position of the wheel. This result is obtained by setting the rudder at an angle to the wheel, so that an increase of the wind velocity tends to turn the whole wheel slightly out

of the wind and thus to reduce the effective area. More sensitive regulation of the speed is obtained by the use of centrifugal governors than with the side-vane arrangement, but the latter is in general sufficiently sensitive, and is preferred by some users on account of its simplicity.

Windmills of the American sectional type were first devised by Daniel Halladay, and one of these Halladay wheels, as manufactured by Alfred

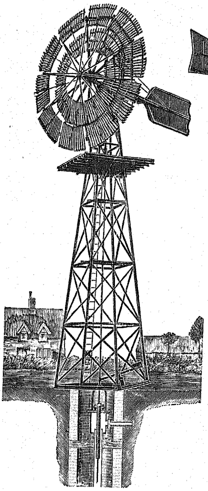


Fig. 471.—The Halladay Sectional-vane Windmill

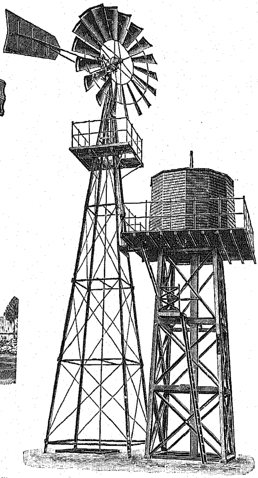


Fig. 472.—The Solid Side-vane Windmill

Williams & Co., of London, is illustrated in fig. 471. It will be seen that the wheel is in sections, each of which is pivoted, and so controlled by a centrifugal governor as to present a reduced area to the wind when its velocity increases. Weighted arms return the sections to their original position when the pressure of the wind again falls. At right angles to the wheel, and in line with the shaft, a rudder is fitted to keep the wheel as a whole in a position normal to the wind. Steel is generally used for

the tower, which is of sufficient height to carry the wheel clear above all surrounding buildings.

In the windmill of the solid side-vane type, illustrated in fig. 472, the slats of the wheel are not movable, and the regulation both of direction and speed is effected by means of a side vane set at an angle to the plane of the main wheel, upon which it acts through a strong intermediate spiral spring. In very rough winds the wheel presents its edge, and as the velocity decreases its face swings back until its full sail area is again acted upon.

CHAPTER II

FUELS

THE NATURAL FUELS.—Owing to the limited distribution of air and water power, and to the variable character of the supplies, only a small proportion of the total power required for industrial purposes is obtained from these natural sources, the greater portion being more indirectly derived from the combustion of the solid and liquid fuels which are found widely distributed over the world. Of the natural fuels—coal, wood, peat, and oil—the most important is coal, but for many purposes the use of oil is becoming very general, not only for the direct driving of internal-combustion engines, but also for the firing of steam boilers. Carbon and hydrogen, with minor quantities of sulphur and oxygen, are the chief constituents of the fuels, and the evolution of heat is the result of the chemical combination or combustion of the carbon and hydrogen with free oxygen derived from the atmosphere. The carbon combines with the oxygen to form either carbon monoxide, $C\,O$, or carbon dioxide, $C\,O_2$ the formation of one or other being determined by the amount of oxygen present and by the temperature. In the complete combustion of the carbon to $C\,O_2$ 14,500 B.Th.U.[1] of heat are evolved, but only 4300 units result from the formation of the lower oxide $C\,O$. From the combination of the hydrogen with oxygen, which together produce water, H_2O, a calorific value of about 62,000 B.Th.U. is obtained. Hydrogen is thus the most valuable constituent of any fuel, and the larger the percentage of this element the greater is the heating value, provided the hydrogen is free and not already combined with oxygen. Sulphur is present in most coals in comparatively small quantities, and its oxidation to the form of sulphur dioxide, $S\,O_2$, results in the evolution of only 4000 heat units, so that, so far as its total heating value is concerned, the sulphur is negligible, but the sulphuric acid which results from the combination of the water and the sulphurous acid has a serious corrosive effect upon the metal of the furnace and boiler, and the presence of sulphur is therefore a disadvantage.

[1] A British Thermal Unit, denoted by the letters B.Th.U., is the quantitative measure of heat, and is the quantity of heat required to raise by 1° F. the temperature of one pound of pure water at its point of maximum density, namely 39.1° F. In metric units the heat unit is called a calorie, 1 calorie being equal to 3.97 B.Th.U.

For industrial purposes the fuels most widely used are coal, wood, and oil, each of which exists in nature in many different forms. There are, of course, many minor sources which are utilized when none other is readily available. Thus, for example, in Cuba, the West Indies, and parts of the United States of America the refuse of the sugar cane, after the extraction of the juice, is very generally used as fuel. This refuse, or, as it is called, BAGASSE, contains a large percentage of moisture, so that the heat available for useful work is not generally more than 30 per cent of that obtainable from average good coal. In many parts of the world there are also extensive deposits of PEAT, which, however, cannot as yet be extensively utilized in competition with coal. When dried in air, peat still contains about 30 per cent of moisture, and the elimination of this amount involves the loss of a considerable portion of the available heat.

WOOD FUEL.—In a thoroughly dry condition there is little difference between the heating values of the various hard and soft timbers, and what difference there is, amounting at the most to 10 per cent, is in favour of the softer woods. In estimating the quantity of wood fuel that may be required, it is safe to reckon the heating value as 0.57, that of ordinary bituminous coal; but, as this is the value for dry wood, it will be necessary to determine the proportion of moisture, which may be as much as 40 per cent, and to make allowance for its evaporation. Where wood is plentiful and cheap it is largely used for heating and the production of steam, but, on account of the small calorific value compared with that of coal, it is necessary to provide a larger grate area.

COAL.—From the analysis of coal, and from the microscopic examination of its structure, it is easy to infer that it has originated in the primeval forest swamps of the Carboniferous period, although the nature of the transition from vegetable or woody fibre to anthracite is not so evident. When wood decomposes in the air its carbon is rapidly consumed, but when it is covered by water and protected from the atmosphere the loss of carbon is less in proportion to the diminution of the oxygen and hydrogen. There is therefore a gradual increase in the proportion of carbon relatively to the hydrogen, and more so to the oxygen, as is indicated in Table I.

Element.	Dry Wood.	Peat.	Lignite.	Splint Coal.	Caking Coal.	Anthracite.
Carbon ...	50	60	68.0	82	87	94.0
Hydrogen ...	6	6	5.5	5	4	2.5
Oxygen ...	44	34	26.5	13	9	3.5
	100 %	100 %	100 %	100 %	100 %	100 %

Moisture and ash have been excluded, as they vary widely according to the district from which the mineral is taken. The ash varies from 3 to over 30 per cent, and the moisture up to 25 per cent. Carbon may exist in coal in the fixed condition, or combined with hydrogen as volatile

hydrocarbons, and in practice the value of a coal is determined by the proportions of the fixed carbon and the volatile matter.

Table II shows how the proportion of fixed carbon increases, and the volatile hydrocarbons decrease, as the mineral lignite changes in time to anthracite.

Fuel.	Fixed Carbon.	Volatile Matter.	Heating Value per Pound of Fuel.
Lignite	Under 50 per cent	Over 50 per cent	11,000 to 13,500
Bituminous ...	50 to 75 ,,	50 to 25 ,,	13,500 to 15,500
Semi-bituminous	75 to 87.5 ,,	25 to 12.5 ,,	15,500 to 16,000
Anthracite ...	92.5 to 97 ,,	7.5 to 3.0 ,,	14,800 to 14,600

Coal in general may be considered as consisting of a combustible portion included in Table II under the headings Fixed Carbon and Volatile Matter, and of certain proportions of ash, moisture, and such impurities as sulphur. A large proportion of ash is objectionable, not only because it reduces the heating value per pound of coal to be burned on the grate, but on account of the formation of clinker, which adheres to the grate bars and obstructs the entrance of air. A large percentage of moisture also diminishes the heating value, as some of the heat is absorbed in vaporizing the excess of water. For several reasons the presence of sulphur, even in small quantities, is objectionable. It corrodes the iron-work, and forms with ash a fusible clinker which clings tenaciously to the firebars.

LIGNITE is a light-brown substance of a distinctly woody texture, and is intermediate between peat and bituminous coal. It readily absorbs a large amount of moisture, and, on account, also, of the large quantity of air required for its combustion, it does not form an economical fuel, as a considerable portion of the heat is wastefully expended in heating the inert nitrogen which accompanies the oxygen of the atmosphere. When burned it gives at a moderate temperature a slightly smoky flame, and it does not readily fuse.

BITUMINOUS COALS contain a considerable proportion of hydrocarbons, which distil readily and burn with a characteristic yellow flame. When the proportion of volatile matter is high the heated coal swells and fuses together, and is said to cake. Non-caking bituminous coal, as the name implies, does not fuse together when heated, owing to the smaller percentage of the hydrocarbons, and it is commonly called "free burning" coal. Bituminous caking coals containing a large proportion of volatile matter are used for the manufacture of gas, the hydrocarbons being distilled in hermetically sealed ovens or retorts. The carbonaceous residue, known as coke, is of the nature of anthracite, which naturally contains but little volatile matter, and it has commercially a considerable value, owing to the intensity of the heat of combustion and the freedom from smoke.

ANTHRACITE, or HARD COAL, burns with a clear, short flame of a

yellow-blue colour, and practically no smoke is evolved during its combustion. This is due, as in the case of coke, to the absence of hydrocarbons, which can only be completely consumed at a considerable temperature and in the presence of sufficient air.

NATURAL OIL.—Natural oil is found in large quantities in the oil regions of North America, Western Canada and Pennsylvania, the Carpathians, and Borneo. It is also found in the Russian territory stretching along the Caspian Sea, particularly at Baku. Smaller quantities are obtained from other districts, such as Scotland, where it is produced by the distillation of oil shales, which contain in addition by-products of considerable value.

PETROLEUM is the general name used to denote the natural mineral oils, which, however, vary considerably in appearance and density. It is in reality a mixture of oils of various densities, which may be separated by fractional distillation, or distillation in stages of increasing temperature. At the lowest temperature the lightest oil, having the highest "flash-point", is driven off, and as the temperature is increased in stages the oils are driven off in the order of their lightness, until at the last are left the heaviest oils or pitch, which can only be consumed at a high temperature.

It is generally agreed that the natural oils have resulted from the heating of adjoining coal beds, but this supposition does not explain the existence of the Pennsylvanian oil, which occurs in beds of sandstone far removed from the rocks of the Coal periods.

Crude oils consist largely of carbon and hydrogen, with small proportions of sulphur, nitrogen, arsenic, and phosphorus, but it may also contain up to 50 per cent of water, according to the situation of the well and the care with which the water has been abstracted.

Petroleum varies in appearance from a thin, colourless liquid, known as NAPHTHA, to a thick, black pitch or mineral tar. In practice the name petroleum is usually reserved to denote the intermediate qualities. The oils from the fields of Western America yield, on distillation, large quantities of PARAFFIN, while those from California and Russia yield ASPHALT and OLEFINE respectively. GASOLINE, BENZINE, KEROSENE, and the other petrol oils used in internal-combustion engines are all driven off at lower temperatures than that required to vaporize the paraffin and heavier oils.

CHAPTER III

STEAM GENERATORS

There are two general methods of converting the heat which results from the combustion of fuel into mechanical work. In the case of gas or oil fuel the energy may be applied directly in the cylinder of an internal-combustion engine, and this is the system which has been extensively developed within more recent years. At the present time, however, the

older system of burning the fuel on the grate of a boiler and of using the steam thus produced to drive an engine is the one still most universally adopted, especially for the development of large powers.

STEAM.—When heat is applied to water the temperature rises until the boiling-point is reached. At the pressure of the atmosphere the water commences to boil when the temperature reaches 100° C.; but ebullition does not commence until the temperature reaches 200° C. when the pressure is further increased by 200 lb. per square inch.

After the boiling-point is reached, the continued application of heat changes the state of the water from the liquid to the gaseous condition; and until the water is completely converted into steam the temperature does not alter. In this condition the steam is said to be saturated. The further application of heat raises the temperature and increases the volume, or the pressure if the vapour is prevented from expanding. Steam which is not in contact with water is said to be dry, and when its temperature is increased above the critical point it is said to be superheated, the degree of superheating depending upon the temperature of the dry steam. It will be seen from the above that a very large proportion of the total heat of steam is latent, and that the internal energy of the steam is much greater than the external energy even when the steam is superheated to a high degree. If the latent heat could be made to increase the external energy it would suffice to make the water red-hot.

HEAT AND WORK.—M. Sadi Carnot, in 1824, first stated the principle that when a heat engine does work the working substance necessarily falls in temperature; but Carnot was not aware that the work was done at the expense of a portion of the heat which thus became transformed. Joule's experiments in 1843 established the doctrine of the conservation of energy, and showed that by the expenditure of 1 British thermal unit 772 ft. lb. of work could be performed, or vice versa. Later experiments have shown the mechanical equivalent of a heat unit to be at least 778 ft. lb., and this is the number that is generally used in practical calculations.

EFFICIENCY OF HEAT ENGINES.—Carnot's proposition has led to the important conclusion that the maximum work obtainable from any heat engine is determined by the quantity of heat in the working substance and by the temperature through which the working substance falls in the operation. If Q be the quantity of heat, and T_1 and T_2 the temperatures at the beginning and the end of the operation, then the work W $= Q(T_1 - T_2)$; and since the whole energy available is equal to $Q\,T_1$, the efficiency $E = \frac{Q(T_1 - T_2)}{Q\,T_1} = \frac{(T_1 - T_2)}{T_1}$, that is, the efficiency of the engine depends upon the initial and final temperatures of the working substance, and the greater the extremes the greater the efficiency. There are unfortunately practical limits to the higher temperature, determined by the corresponding pressure and by the action of the working substance at high temperatures on the metal parts of the engine and boiler. The lower temperature is also limited by the natural temperature of the air or water into which the heat is rejected.

REQUIREMENTS OF A GOOD BOILER.—Steam boilers or generators of

endless variety have been devised to meet the very varied conditions of actual service; but it is generally possible to include any boiler under one or other of certain definite types, and a detailed description of many special designs is therefore unnecessary.

Where the accommodation is not limited, or where the demands for steam do not fluctuate rapidly, a simple type of boiler is generally adopted; but where the space is restricted, and the demands for steam vary suddenly and within wide limits, it is necessary to adopt a more complicated type.

A good steam boiler should possess as many of the following qualities as possible, but the conditions may necessitate the sacrifice of certain of them.

1. It should always be constructed of the best materials available, and the workmanship should be good.

2. It should be properly proportioned for the work to be done, and be capable of working at its best efficiency at the normal load.

3. The design should involve as few parts and joints as possible, provided other conditions are satisfied, and the parts should be free to expand when the temperature fluctuates; otherwise the boiler will require constant attention and repair, and the danger of explosion will be increased.

4. A constant circulation should be maintained in all parts so that the temperature may be uniform everywhere.

5. A large water surface should be provided so that the steam will be disengaged without excessive foaming or "priming".

6. The capacity of the steam and water spaces should be large enough to prevent serious fluctuations of the pressure and the water level.

7. The grate area and the heating surface should be proportioned to the power required, and the heating surface should be so disposed that the hot gases impinge upon it and readily give up their heat.

8. The combustion chamber should be sufficiently ample for the complete combustion of the gases, and the surface should be arranged so as fully to extract the heat, with the exception of what is required to maintain the draught in the chimney.

9. All internal parts should be readily accessible for inspection, cleaning, and repair, particularly those parts directly exposed to the hot gases. External parts should in the same way be open to inspection, and precautions should be taken against the accumulation of moisture along the external seams.

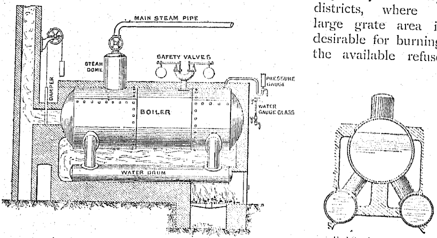
10. When a mud drum is provided it should be placed as far from the direct action of the fire as possible.

11. For safety the gauge glasses and safety valves should be duplicated.

DEVELOPMENT OF THE BOILER.—In the early days of steam generation at the commencement of the eighteenth century the working pressure of steam boilers did not exceed 5 lb. per square inch as compared with pressures of 300 lb. at the present time, and in 1800 Brindley introduced a boiler having a thick granite shell traversed by an internal copper smoke flue. James Watt also about the same time found a hooped wooden shell sufficient for the steam pressures then in common use. About the year 1785 the wagon type of boiler was very generally em-

ployed with satisfactory results, considering the comparatively low pressures of from 25 to 30 lb. and the flatness of the surfaces. They were fired externally on the under side, but the gases were carried back to the front through return flues. Frequently the length was 25 ft. and the height 7 ft.; but, apart from the inherent weakness of the design, these boilers are unsatisfactory from the point of view of economy of fuel.

With the further rise of steam pressures it was found necessary about the year 1800 to introduce the EGG-ENDED BOILER, which, owing to its cylindrical and hemispherical shape, was better suited to resist a high internal pressure. They were externally fired, and at the present day examples of such boilers may still be seen at work, especially in colliery districts, where a large grate area is desirable for burning the available refuse coal. French engineers developed the egg-end form with considerable success by adding lower water drums connected to the upper vessel by limbs, as shown in fig. 473. This form is commonly known as the FRENCH OR ELEPHANT TYPE.



Arrangement of Elephant Boiler with "Bouilleurs" — End Section of Elephant Boiler with "Bouilleurs"

Fig. 473

An important advance was made in 1804, when the CORNISH BOILER was introduced in the mining districts of Cornwall, from which the name was derived. As shown in fig. 474 it consists of a cylindrical outer shell with a single internal flue, the front portion of which contains the grate, while the rear serves as the combustion chamber. At the present day the LANCASHIRE BOILER, which has two flues (fig. 475), is greatly favoured for land purposes where rapid steaming is not a first consideration. It is simple in construction and reliable in action.

In the Galloway type of boiler the two furnaces are joined to form a common combustion chamber, which is traversed by conical GALLOWAY TUBES. These tubes help to break the flow of the gases, and bring the water into more intimate contact with them. They also assist the circulation and serve to strengthen the flue, which otherwise would be of too weak a form to withstand the pressure. A Galloway boiler 28 ft. long and

7 ft. in diameter will evaporate about 6000 lb. of water per hour, and will supply sufficient steam to drive a modern compound engine of 300 i.h.p.

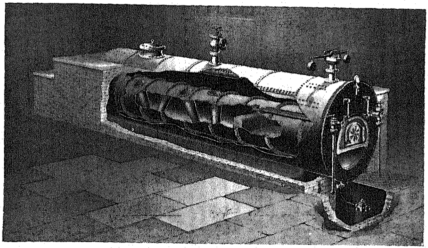


Fig. 474.—Single-flue Cornish Boiler

In the case of the boilers illustrated in figs. 474 and 475 it will be seen that the gases pass through the boiler to the back, then externally

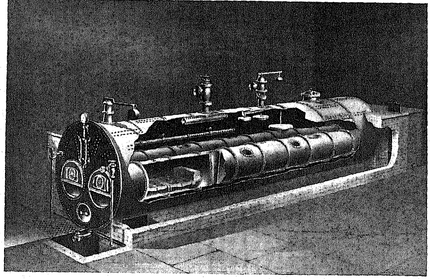


Fig. 475.—Lancashire Boiler

along either side to the front, and again to the back, but this time underneath the boiler before they pass away to the chimney. This is done to utilize the heat of the gases as completely as possible.

When it is desired to increase the heating surface still further, the gases are carried back through the boiler in a large number of smoke tubes. In comparison with the space occupied, MULTITUBULAR BOILERS of this kind give a large power; but the efficiency can only be maintained so long as the tubes remain unobstructed by soot internally and scale externally. There is too frequently inadequate provision made for thoroughly removing such deposits, and a further difficulty is often experienced at the junctions of the tubes and the end plates, which are liable to leak when the boiler is subjected to sudden variations of temperature.

LOCOMOTIVE BOILERS afford a good example of the power attainable when the space is very limited, as it is in locomotive practice of the present day. The "locomotive" type of boiler consists of a cylindrical shell, with a firebox at one end and a smokebox at the other, connected by numerous small-diameter smoke tubes. Some of the heat is transmitted directly to the water in the spaces around the sides and top of the firebox, and the remainder is given up in the passage of the gases through the smoke tubes which traverse the water space of the boiler. Further reference will be made to this type of steam generator when dealing with the locomotive.

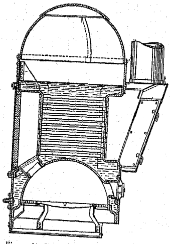


Fig. 476.—Vertical Multitubular Portable Boiler

PORTABLE BOILERS are frequently required for small powers where the space is very restricted and where the transport facilities are limited. They are also used for temporary works and as donkey boilers on board ships. A vertical multitubular boiler, as manufactured by Messrs. Cochrane & Co., of Annan, is illustrated in fig. 476, from which it will be seen that the crown of the furnace is formed of a single pressed plate with two flanged apertures, one for the exit to the combustion chamber, and one for the fire-door. The smoke tubes are arranged horizontally between the combustion chamber and the smokebox, from which the chimney rises; but in some cases the chimney traverses the steam space diagonally, and passes through the top of the boiler. It will be evident that the chief difficulty in such boilers is to keep the gases sufficiently long in contact with the water to fully extract their heat; but a very fair economy is obtainable, considering the smallness of the total space occupied and the power of the boiler.

For marine purposes the CYLINDRICAL or "SCOTCH" BOILER has been almost exclusively adopted in the merchant service, but this is not so in the navy, where considerations of rapidity of steaming, and to some extent weight, have determined the use of water-tube boilers. The Scotch boiler (fig. 477) consists of a cylindrical shell with large flat ends stayed together by long tie-rods. The furnaces, varying in number from three to

five or more, according to the size of the boiler, pass from the front plate to the combustion chamber, which is completely enclosed in the cylindrical shell and surrounded by the water. Smoke tubes pass from the combustion chamber back to the front plate of the boiler and open into the smoke uptake which communicates with the funnel. There is generally one combustion chamber for each of the furnaces, with water spaces between them. In the case of large-powered boilers the diameter of the shell may be from 14 to 17 ft., and when the pressure is 300 lb., as is frequently the case, the thickness of the steel plates required to withstand the pressure is as much as $1\frac{3}{4}$ in. For manufacturing reasons it is unlikely that the size of these boilers will be much increased in the future. Single-ended boilers have furnaces which open from the front of the boiler only, but marine boilers are sometimes double-ended and fired both at the front and the back. The furnaces then open into combustion chambers in the middle, and the smoke tubes return to the uptakes at each end. Owing to the large volume of water which these boilers carry at one time there is great danger of disaster whenever an accident happens, as, for example, when the furnace or the combustion chamber becomes ruptured.

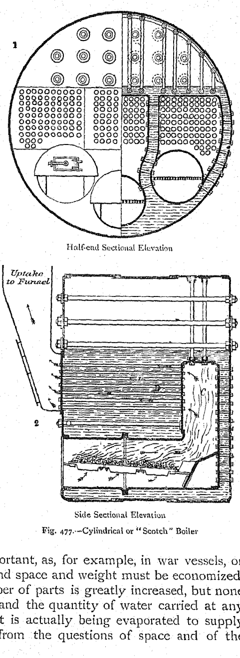


Fig. 477.—Cylindrical or "Scotch" Boiler

WATER-TUBE BOILERS.—Water-tube boilers are generally employed whenever space is limited or where ground is costly, as in large towns. They are also extensively adopted where rapid steam-raising is important, as, for example, in war vessels, or where a large power is required and space and weight must be economized. In the water-tube boiler the number of parts is greatly increased, but none is of a large diameter or weight, and the quantity of water carried at any instant is little in excess of what is actually being evaporated to supply the demand for steam. Apart from the questions of space and of the

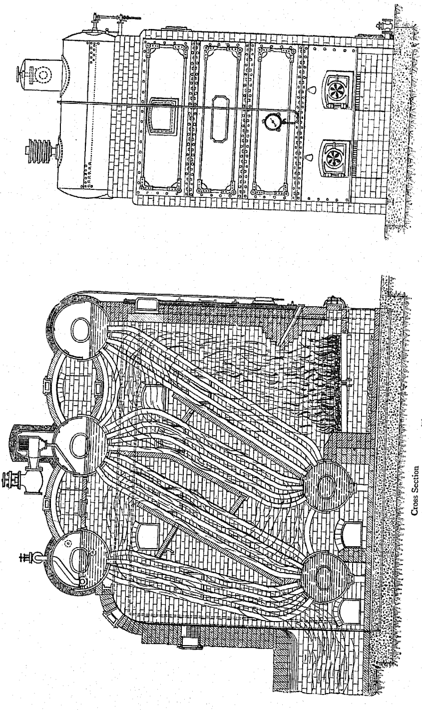
rapidity with which steam can be raised without straining the boiler, there are other important features which can only be briefly referred to here.

As the diameter of the largest steam drum of a water-tube boiler rarely exceeds 4 ft., it is possible to make the plates of well-rolled and homogeneous materials, and the danger of serious fracture of any part is small, and by reason of the small quantity of water contained in the boiler an explosion cannot be so disastrous as in the case of boilers having large water spaces. If the fracture should take place in one of the small-diameter water tubes the result would be even less serious, as the quantity of water that could escape through the small tube bore is necessarily limited.

CIRCULATION AND UNIFORMITY OF TEMPERATURE AND RAPIDITY OF STEAMING.—Owing to the rapid and the definite nature of the circulation in water-tube boilers, the temperatures of the parts do not vary much, and there is less danger of unequal expansion and straining. As a result steam can be raised more quickly without fear of damage, and the evil effects of fluctuations of temperature are not so serious. Owing, also, to the thinness of the plates and tubes, the boiler responds readily to an increase of the furnace temperature, which makes it particularly suitable for certain services, as, for example, lighting-station work, where the load may be suddenly doubled, as a result of fog or other change in the weather.

To William Blakey, a contemporary of Watt, is credited the first water-tube boiler, introduced by him in 1766. It consisted of several tubes inclined in opposite directions over the furnace, and connected at their ends by cross tubes. Since the introduction of Blakey's boiler, which gave no results of practical importance, tubes of endless variety have been tried with more or less success. Some designers prefer numerous small-diameter water tubes, while others advocate fewer tubes of a larger diameter. Straight tubes, bent tubes, and coils are also made the features of particular boilers which are claimed by the individual makers to meet satisfactorily most conditions of service.

The BABCOCK AND WILCOX BOILER, now being extensively used for marine purposes as well as on land, is a development of the boilers built in 1856 by Stephen Wilcox. It consists essentially of vertical rows of inclined tubes, staggered in such a way that the gases, in their passage through the rows, are compelled to take a zigzag course and to impinge upon each of the tubes. Each row is connected with the steam drum, lying horizontally above the boiler, by means of special headers or boxes. This arrangement of inclined tubes, steam and water drum, together with the headers and their connections, is clearly shown in the Plate, which also shows the arrangement of the grate and the brickwork. The boiler is suspended from wrought-iron girders resting upon iron columns, and is entirely independent of the brickwork, which is therefore free to contract or expand without constraining the boiler itself. This arrangement is also convenient when repair of the brickwork is necessary. Diaphragms of refractory brick are placed, as shown in the illustration, around the tubes, to prevent the escape of the gases



Front Elevation

Cross Section

Fig. 478.—Stirling Boiler (five-drum type)

directly to the chimney and to prolong their path in contact with the tubes. In the example given the fire is automatically stoked, and the fuel is carried slowly from the front to the back upon the slowly moving grate bars, which form a continuous belt driven automatically by the front drum. For cleaning and repairing, the whole grate can be drawn forward on rails provided for the purpose.

In the STIRLING BOILER, fig. 478, no headers are used, and the number of small parts and joints likely to give trouble has been reduced as far as possible. It consists of groups or "banks" of long and steeply inclined tubes connecting three upper steam drums with common lower or mud drums. Suitably disposed baffle plates constrain the gases from the furnace to pass along the banks of tubes. Short tubes connect the steam spaces of the three upper drums to ensure equality of pressure throughout, and the water spaces of the front and the middle drums are also connected. As in the previous boiler described, the entire weight of the boiler and its contents is carried upon a steel framework independent of the brickwork setting.

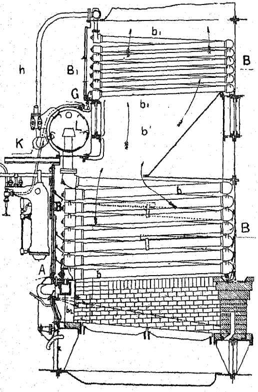


Fig. 479.—Belleville Water-tube Boiler

For warship purposes numerous other types have been specially designed to meet the unusual conditions which exist on such ships. Of these types the most extensively adopted in the navies of the world is the BELLEVILLE WATER-TUBE BOILER, illustrated in fig. 479. It consists of a series of tubular elements, arranged side by side, each of which comprises two vertical rows of tubes, inclined in opposite directions at a slight angle of 3 degrees, and connected together by means of coupling boxes so as to form a continuous passage for the water from the common feed collector at the bottom of the front end to the steam drum at the top. Above the main boiler and the combustion chamber is arranged a similar but smaller series of tubes known as the *economizer*. The feed water from the pumps passes through an automatic feed regulator at the front of the boiler into the distributing box at the bottom of the economizer, through the tubes of which it rises

to the exit at the top. From the economizer the heated feed water passes through a non-return valve to the steam drum, and then down to the feed collector, from whence it passes into the elements of the boiler proper.

The NICLAUSSE BOILER consists of tube elements placed with a slight inclination over the fire grate, but it differs from other types in having the tubes of a duplex type connected, at the forward end only, to headers divided into two portions by diaphragms. Each of the outer tubes is sealed at the back end, and encloses an inner tube which opens into the front section of the header, while the outer tube is in communication with the other portion. Above the boiler is placed the water drum, with an upper steam dome from which the steam is drawn off.

A somewhat similar boiler of German origin is the DÜRR BOILER, which has concentric or duplex tubes and a superheater placed in this case at the top of the boiler in direct communication with the steam space of the drum. In the French navy the LAGRAFEL D'ALLEST type has been extensively adopted. In some respects it resembles those already described, but it has flat water spaces at the front and back, into which the inclined water tubes are connected, and the water drum is larger. A characteristic feature is the arrangement of the boilers in pairs with the combustion chambers between them at the sides of the tubes.

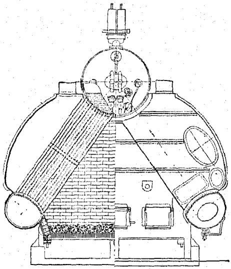


Fig. 480.—Yarrow Water-tube Boiler

THORNYCROFT - SCHULTZ BOILERS are characterized by the arrangement of their numerous small-diameter tubes, the greater proportion of which discharge into the steam drum at a higher level than that of the water. It is claimed that with this arrangement and the use of baffle plates there is greater freedom from priming, and that the steam obtained is drier. In the NORMAND BOILER, small-diameter bent tubes are also used, but they enter the steam drum below the water level. This is also the case in the REED BOILER, used extensively in the British navy, but the tubes are bent more, to facilitate the disengagement of the steam bubbles from the heating surface. Four large external headers connect the lower drums with the water space of the upper, and at the same time serve as part of the framework.

Bent tubes form a very flexible arrangement, the joints of which are not readily strained by unequal expansion. They also facilitate the disengagement of the steam and promote the circulation. On the other hand, they are difficult to clean internally and externally, and the removal or replacement of a tube is not easy. These objections do not hold in

the case of the straight-tube types, one of which, the YARROW BOILER, is illustrated in fig. 480. It consists of an upper drum, into which the two sets of straight tubes are expanded under the water level. In the WHITE-FORSTER BOILER the tubes are slightly curved to determine the direction in which they will bend when expansion takes place.

Water-tube or Express boilers do not contain a large quantity of water beyond what is required for the momentary production of the steam. There is, however, another class which practically contains no store of water. They are known as FLASH BOILERS, and are commonly used in steam motor cars on account of their safety under any pressure and by reason of the power obtainable from a comparatively small weight of boiler. Generally they consist of a continuous coiled tube having walls of great thickness in proportion to the water space. By means of a powerful burner the walls are maintained at a high temperature, and the water, as soon as it enters, flashes into steam. When dealing with the subject of the motor car, these boilers, with their automatic controlling arrangements, will be described in more detail.

CHAPTER IV

STEAM ENGINES

HORSE-POWER.—Some reference has already been made to the thermal and elastic properties of steam when dealing with the subject of steam generation, and it now only remains, before describing the various types of engines, to explain in a general way the action of the steam in the cylinder or expansion chamber of an engine.

When steam acts upon a loaded piston a certain quantity of mechanical work is developed at the expense of the heat energy of the steam in moving the piston. If, for example, the volume of the cylinder be V, and the steam pressure required to overcome the load on the piston be P, then the energy expended will be the change of volume multiplied by the pressure, which is supposed to be kept constant by the continuous admission of steam. If, then, W represents the work done per stroke, $W = V P$, but the volume is the area A multiplied by the length of the piston stroke L, so that $W = P L A$. This, then, represents the energy expended during one stroke of the piston, and it will be seen that the element of time does not enter into the equation. For the practical comparison of different engines it is necessary to know the rate at which the work is developed, and to express this rate the term "power" is generally used. One minute is the unit of time adopted, and therefore, in the above example, if the piston makes N working strokes per minute, the power $= P L A N$. In the early days of the steam engine it was soon found desirable to have some standard power for purposes of comparison, and the most natural, although indefinite, standard appeared to

be the horse, which was being displaced by the engine. James Watt followed Savery in the use of the horse as a standard, and made numerous tests to determine the average power of a horse. As a result of his tests the horse-power, or H.P., is considered as being equivalent to the development of 33,000 ft. lb. of work per minute, but this is really 30 per cent in excess of the actual average amount determined by him. By dividing the power of the engine by the standard power of the horse the horse-power of the engine is then obtained, thus: $\text{H.P.} = \frac{PLAN}{33,000}$.

EXPANSIVE WORKING.—Advantage is taken of the elastic energy of steam by cutting off the supply to the cylinder after a certain interval, so that the remainder of the stroke takes place under the action of the expanding steam. In this way a larger proportion of the energy is abstracted as the steam is exhausted at a lower temperature. It should be noted, however, that although there is greater economy the power obtained from the engine is less, since the average pressure is now smaller than the initial pressure which before was supposed to act throughout the stroke. Great flexibility of power results from this system of expansive working, because the power of the engine may be largely increased when desired by cutting off the steam at a later period of the stroke.

TYPES OF STEAM ENGINES.—In practice the design of an engine is determined by the conditions under which it will be required to work. For pumping plants where a slow speed is desirable a long-stroke slow-revolution engine is preferred, whereas for the direct driving of dynamos, and in situations where space is limited, quick-revolution or, as they are frequently called, high-speed engines are generally employed. Economy of consumption, as well as economy of material and simplicity of construction, are also factors of great importance.

Referring again to the equation of the horse-power, $\text{H.P.} = \frac{PLAN}{33000}$, in which N is the number of working strokes per minute, it will be seen that since in the single-acting engine there is only one working stroke per revolution, while in the double-acting engine there are two, the power of the latter will be approximately doubled without correspondingly increasing the weight of the engine. As a first general classification, therefore, steam engines may be considered as being either single or double acting, but the great majority are now of the latter type.

By altering the value of the steam pressure P, the power may be varied in proportion, and some gain may be obtained without an increase of the initial pressure by reducing the back pressure on the piston. Under the simplest conditions, when no condenser is fitted, the back of the piston is subjected to the pressure of the atmosphere, and the working pressure is therefore less by that amount. By the addition of a condenser, into which the steam is exhausted and liquefied, the pressure behind the working face of the piston may be reduced to within a few pounds of a complete vacuum and the effective working pressure increased by about 12 lb.

A large supply of cold condensing water is required, and pumps are necessary for its circulation and for the extraction of the condensed steam

and vapour. It may happen, especially where suitable water is scarce or costly, that the gain in economy is largely counterbalanced by the extra costs of working the auxiliary plant, and in many land installations condensers are accordingly dispensed with. The power of an engine may be increased indefinitely within practical limits by increasing the value of N, the working strokes per minute, and this is the system that is generally followed. In the same way the size of the engine for a given power may be decreased by increasing the speed of revolution, and the decrease in weight does not vary merely in a simple ratio, as the forces to be carried by the parts are smaller.

Steam engines may be SINGLE-ACTING or DOUBLE-ACTING, CONDENSING or NON-CONDENSING, or they may be of a QUICK-REVOLUTION or a SLOW-REVOLUTION type. In the description of the various constructions which follows, the last classification has been adopted, as an engine may be run either with or without a condenser as desired, whereas the quick or slow speed of rotation determines the whole design. Very frequently the term high-speed is used instead of quick-revolution; but this term may lead to confusion when considering the question of piston speed, since two engines having very different speeds of rotation may be designed to run at the same piston speed by making the stroke of the slow engine long and that of the quick-speed engine correspondingly short.

So far no account has been taken of the thermal conditions, which play an important part in the design from the point of view of economy of steam. When steam expands in the cylinder of an engine its temperature falls, and when the range between the initial and final temperatures is great a considerable amount of condensation takes place at an early stage of the expansion and the efficiency is thereby affected. This appears to be largely due to the fact that the entering steam becomes chilled by contact with the cylinder walls, which have been previously reduced to more nearly the temperature of the exhaust. If the difference is considerable, condensation very readily takes place, and it is found that the presence of a very small quantity of water has a serious effect in producing further condensation. The question is, however, a complex one, and many of the phenomena of condensation are not yet fully understood. To limit the size and to reduce early condensation losses, the expansion of the steam is carried out in two or more consecutive cylinders, in each of which the range of pressure and therefore the range of temperature is less. Engines are said to be of a SINGLE, COMPOUND, TRIPLE, or QUADRUPLE EXPANSION type, according as the steam is expanded in one, two, three, or four stages. It should be noted that there are generally more cylinders than stages of expansion, as two low-pressure cylinders of moderate diameter are often preferred to one of large diameter.

EARLY STEAM ENGINES.—To the Marquis of Worcester is generally credited the idea of utilizing in a practical way the expansive force of steam; but there is no trace of his work beyond the description which he published in 1655 as the sixty-eighth invention in his book entitled "The Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected". Earlier attempts to utilize the energy of

steam were based upon the reactive forces of jets, and the first recorded example of a machine for utilizing steam is the Eolipile, devised by Hero of Alexandria about 130 years before the advent of Christ.

In 1628 Giovanni Branca published an account of an eolipile which was actually applied to a useful purpose. These examples are particularly interesting in their bearing upon the present-day development of the steam turbine, in certain types of which the primitive idea of the eolipile is involved. Captain Savery obtained in 1698 a patent for an engine which differed but little in principle from the engine of the Marquis of Worcester. It comprised a cylinder into which the steam was allowed to enter, and thus to force out the water sucked into it by the condensation of the previous charge of steam. Many of these engines, improved in details, were erected by Savery in different parts of the country for pumping water, and at the present day pulsometer pumps based on the same principle are extensively used for similar purposes. Newcomen further improved the steam engine by introducing a piston which was driven down by the pressure of the atmosphere when a vacuum was created on the other side by the condensation of the steam in the cylinder.

JAMES WATT.—In all these early engines the condensation of the steam took place in the cylinder itself, and it was not realized what an amount of steam was wastefully consumed in consequence until James Watt investigated the subject. He found, as a result of experiments with a small working model of a steam engine which belonged to the University of Glasgow, by whom he was engaged as a mechanic, that 75 per cent of the steam was expended in heating the walls of the cylinder at each stroke. By substituting a cylinder of wood, and later of metal lagged with non-conducting materials, and by curtailing the quantity of water injected, he was able to reduce the loss to 50 per cent; but these results were quickly surpassed by the invention of the separate condenser, by means of which an almost complete vacuum was obtained without reducing the temperature of the cylinder walls much below that of the working steam. It is well realized at the present day how much the progress of the world has been determined by the improvements effected by James Watt in the economy of the steam engine.

ROTARY ENGINES.—Numerous attempts have been made to devise an engine which would produce direct rotational motion, and thus dispense with all the gear required for the conversion of the reciprocating motion of the usual type of steam engine; but no successful results have been obtained, notwithstanding the attention and labour that have been expended on the problem. This is chiefly owing to the difficulty of preventing the leakage of steam past the line contacts, which is almost inherent in engines of such a type. It is true that the steam turbines of the present day produce direct rotary motion, but it will be seen later that in principle the two types are actually very different.

RECIPROCATING ENGINES.—A steam engine consists essentially of a working cylinder and piston, with the gear necessary for the transmission of the motion to the shaft; an automatically operated valve for distributing the steam; and a governor for controlling the speed within the desired

limits. In addition, the engine may be fitted with a condenser, in which case certain auxiliary pumps are required. Compound and multiple-expansion engines may be considered as a combination of two or more engines; but certain portions, as, for example, the condensing plant, may be common to all. From the illustration (fig. 481), which indicates in sectional plan the relative positions of the various parts of a simple horizontal engine, it will be seen that the distribution valve is placed at the side of the cylinder and is operated by an eccentric on the crank shaft. The valve is of the common slide or D type, a development of the long D valve introduced in the early engines of the time of Watt. As the valve moves over the steam ports it alternately places each side of the piston in communication, first, with the steam supply, and then with the exhaust or

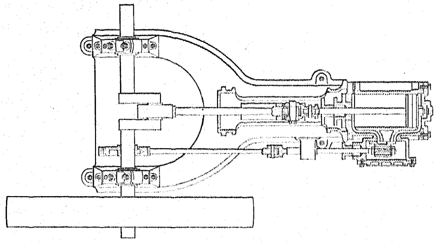
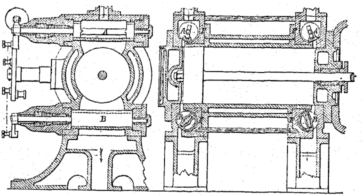


Fig. 481.—Sectional Plan of a Simple Horizontal Steam Engine

the condenser; and it also controls the times and amounts of the steam admission, cut-off, exhaust, and compression. Thus the steam is admitted to the cylinder before the piston has reached quite the end of the stroke, in order to effect without shock the change in the direction of the reciprocating motion of the piston; the steam admission is cut off before the middle of the stroke, in order to utilize its expansive force; the exhaust passage is opened at the end of the stroke and closed just before the completion of the return stroke, so as to cushion the piston and again gently change its direction of motion. These and other minor effects are obtained by setting the eccentric which works the slide valve in advance of the crank by an angle which slightly exceeds 90 degrees. The governor is generally of a centrifugal type driven from the crank shaft and arranged to control a throttle valve placed in the steam-admission pipe; but a flywheel increases the regularity of the rotation, and is an essential feature when the load fluctuates considerably. Precautions must be taken to prevent the loss of heat through the cylinder walls, which must either be lagged with non-conducting materials or jacketed with live steam, in which case the jackets must be efficiently drained, as otherwise the

accumulation of water in them may result in more loss than gain through condensation in the cylinder.

VALVES.—One disadvantage of the simple slide valve lies in the close contact of the high-temperature admission steam with the low-temperature



Cross Section Sectional Elevation

Fig. 482.—Cylinder of Steam Engine, showing arrangement of Corliss valves

exhaust. It will be seen that the same passages serve alternately for the admission and the exhaust, and that serious condensation is likely to occur in consequence. When economy is of more importance than great simplicity, separate valves are provided for the admission and the exhaust, as shown in fig. 482, which is an illustration of a Corliss engine in side and end section. Admission valves A A of a "rocking" type enclosed in the cylinder ends F F are placed at each end of the upper side of the cylinder, which is generally arranged horizontally, and exhaust valves B B of the same kind are placed at the bottom ends, where any steam condensed in the passages readily drains away. Each valve is separately connected to a "wrist" plate, shown in the cross section, which opens and closes them in the required order. Usually the exhaust valves are connected directly to the wrist plate, but a "trip" gear is inserted in the connections to each of the admission valves, as improved economy is obtained by closing the valves very sharply instead of gradually. As the name implies, the trip gear is caught at a certain point and caused to release the arms of the admission valves, which then close sharply under the action of strong springs. A side view of the Corliss gear is shown in fig. 483. D D are spring blades which,

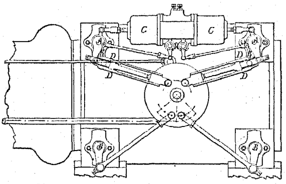


Fig. 483.—Side View of Inglis & Spencer's Corliss Gear

when forced apart by the trip-gear arms E, disengage the valve levers and allow the valves to be sharply closed under the action of the springs in the boxes C C. Owing to the difficulty of efficiently lubricating the working surfaces of the Corliss rocking valve, and to the

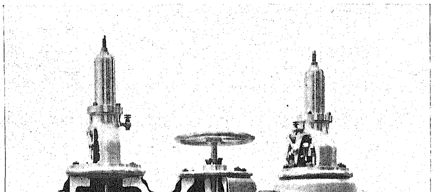
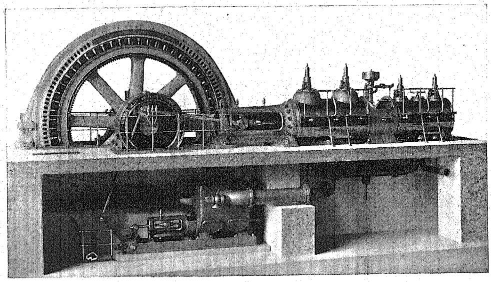
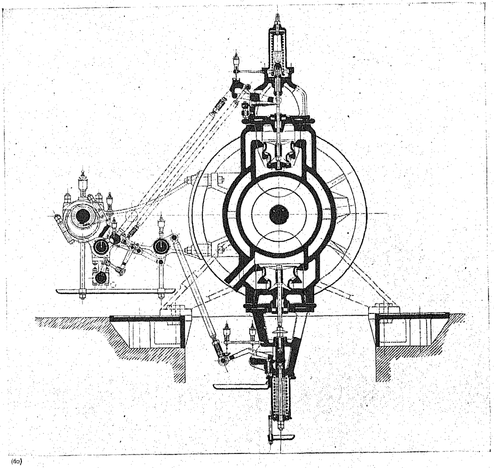


Fig. 484.—Half-sectional Elevation of a Sulzer Engine Cylinder, showing the arrangement of the double-beat valves

wide range of spring adjustment required when the steam pressure is high, valves of the Cornish or double-beat type are now most frequently adopted. Valves of this description as used in the tandem-compound engines made by Sulzer Bros., of Switzerland, are illustrated in the Plate and in fig. 484. The transverse section illustrated in the Plate is a section





(62)

HORIZONTAL TANDEM CONDENSING ENGINE COUPLED DIRECT TO ALTERNATOR

AND A TRANSVERSE SECTION THROUGH THE ENGINE CYLINDER AND VALVES
MANUFACTURED BY GEBRÜDER SULZER, WINTERTHUR, SWITZERLAND

through the cylinder and one pair of valves, and shows the details of the trip gear, driven in this case from eccentrics carried upon a valve shaft at one side of the engine. In fig. 484 part of the cylinder has been cut away to expose the valves at one end, but the illustration also clearly shows the steam ports, passages, and jacket arrangements. The side elevation illustrated in the Plate is an external view of the engine coupled to a large alternator, the condenser being shown in the pit underneath. At high speeds there is considerable shock each time valves of this type close, especially when the adjustment is not good. This objection does not hold in the case of piston valves, which are now frequently adopted in high-speed engines, but trouble may be experienced through unequal expansion of the valve and the liner when superheated steam is used.

VALVE GEARS.—Mention has already been made of the trip gears used in engines fitted with separate admission and exhaust valves, and it only remains to describe briefly the essential features of the various

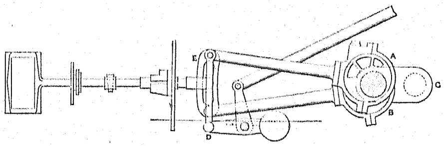


Fig. 485.—Stephenson Link Gear

gears used in conjunction with slide valves. Of these the most frequently used, and from many points of view the most satisfactory, arrangement is the so-called STEPHENSON LINK GEAR, fig. 485, which was really invented by an engineer, Howe, in the employment of Stephenson. Two purposes are served by the Stephenson and other gears. They not only time the distribution of the steam, but they also enable the motion to be reversed by raising or lowering the link E by means of the lever D until one or other of the eccentric rods is in the full controlling position in line with the valve spindle, in which case the only effect of the other eccentric is to swing the link idly about its opposite end without affecting the motion of the valve. When the link is in its mid position the opposite motions of the eccentrics A and B counteract one another and the valve remains stationary. By placing the gear in mid position it is thus possible to stop the engine without actually cutting off the steam supply. Since the valve has its full travel when the link is at either end, forwards or backwards as the case may be, and has no travel in the mid position of the link, it will be evident that for intermediate positions the valve will have a corresponding travel, and that the steam supply will be cut off at an earlier or later period of the stroke. An alteration of the point of cut-off in this and other similar gears means a corresponding alteration of the period of release, and it is difficult

for this reason to satisfactorily cut off at a point earlier than one-third of the stroke. Radial gears, of which the Joy, Hackworth, and Marshall arrangements are typical examples, require one eccentric only, and a curved, adjustable guide is substituted for the slotted link. In the JOY GEAR, fig. 486, there is no separate eccentric required, as the elliptic motion of a point on the connecting rod A B is made to serve the same purpose. From the illustration it will be seen that the motion of the valve rod connected at H to the combining lever H G D is a resultant of the motion of the point C, which approximately synchronizes with that of the piston, and of the motion of the point E which swings about the fixed point F, together with a small displacement due to the movement of the pivot G in the curved guide, which serves for the reversal of the gear and for the alteration of the point of cut-off. Better results are obtainable with gears of this kind than with the Stephenson link motion, especially when the cut-off takes place early.

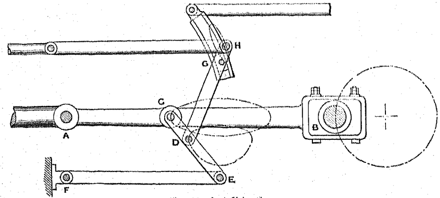


Fig. 486.—Joy's Valve Gear

CONDENSERS.—Two types of condensers are customarily used in conjunction with engines of larger powers when steam economy is of first importance, and when suitable water is obtainable at a reasonable cost. When the water is pure it may be brought into direct contact with the exhaust steam to be condensed, but when the water is impure, and when the condensed steam is used for feeding the boiler again, they must not be allowed to come into direct contact, as the presence in the boiler of water which may contain acids or grease is very objectionable. In the former case a JET CONDENSER of the type shown diagrammatically in fig. 487 is used. The exhaust steam enters at the top of the condenser chamber, and is liquefied in contact with the cooling water which is injected through the slotted pipe shown. Underneath the condenser chamber is arranged an air pump, which extracts the condensed steam, water vapour, and cooling water, together with any air that may have leaked into the low-pressure system, and forces them into the hot well at the bottom, from which the boiler is fed. In this way the air pump maintains a high vacuum and reduces the back pressure on the piston. SURFACE CONDENSERS depend

upon the cooling action of metal surfaces maintained at a low temperature by the circulation of cold water which never comes into direct contact with

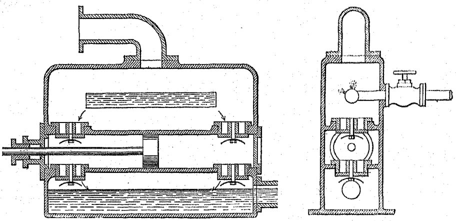


Fig. 487.—Jet Condenser and Pump

the steam. A separate surface condenser of the Wheeler type is illustrated in fig. 488, which shows the condenser in section carried over the pumps. At the right-hand side will be seen the water pump for circulating the

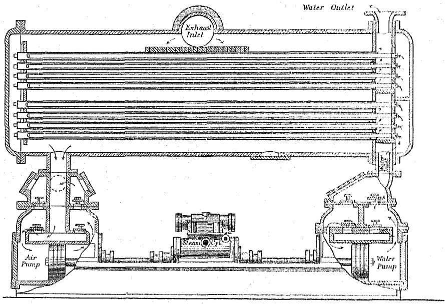


Fig. 488.—Wheeler Surface Condenser

cooling water, first through the lower group of tubes, then through the upper, and away through the water outlet to the coolers, from which it is returned to the circulating pump when the supply is limited. Exhaust

steam from the engines is admitted at the top, and is condensed in contact with the cold surface. At the lower left-hand side is shown in partial section the air pump which maintains the vacuum, and between them will be seen the small engine coupled directly to both pumps.

MULTIPLE-EXPANSION ENGINES.—By dividing the total range of expansion over two or more cylinders the condensation losses are reduced and the economy is improved, but there are other advantages of considerable importance. When the engine is large it is convenient to divide the power over several cranks, as the weights of the moving parts are reduced and a more uniform turning effort is obtained; thus, in the

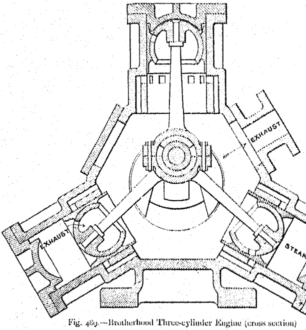


Fig. 489.—Brotherhood Three-cylinder Engine (cross section)

case of compound engines, the exhaust from the high-pressure cylinder may be expanded in two low-pressure cylinders of more moderate diameters, the three cranks being set at 120 degrees apart. Expansion of the steam can then be carried further, since the total low-pressure capacity may be increased. When the steam pressure is great it is necessary to adopt triple- or even quadruple-expansion engines in order to avoid an excessive range of expansion in any one stage.

QUICK-REVOLUTION OR HIGH-SPEED ENGINES.—At an early stage in the development of the electrical industry it was found desirable to have an engine capable of running at the high speeds required, and the quick-revolution type of engine now so commonly used was gradually evolved to meet the new conditions. Apart from the question of speed of rotation, the small size and the lightness of the moving parts are features which make such engines a necessity for many purposes besides the running of dynamos.

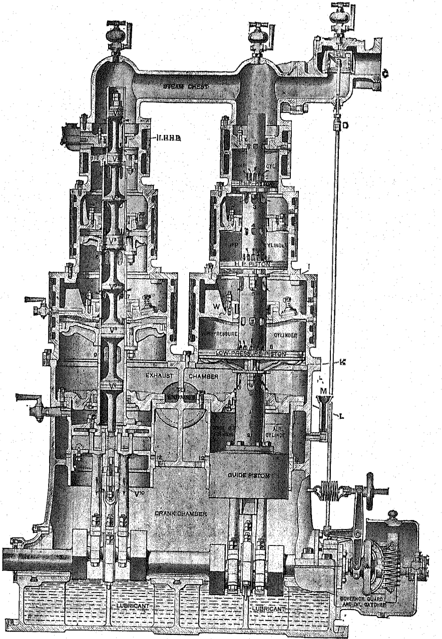


Fig. 490.—Two-crank Triple-expansion Willans & Robinson Central-valve Engine (sectional elevation)

In 1873 Mr. Brotherhood introduced what may be considered as the first of the quick-revolution class of engines shown in the cross sectional elevation (fig. 489). There are in this engine three pistons arranged at 120 degrees apart and coupled to one crank. At the sides of the

cylinders are placed piston valves, which are driven from a common eccentric and control the admission of steam only. Exhaust takes place through ports in the cylinder walls, which are uncovered at the end of the piston outward stroke, but a supplementary exhaust port—which remains open for a portion of the return stroke—is provided in the oscillating spherical portion of the bucket piston. It will be seen that although the engine is single-acting, the three cylinders ensure sufficient regularity of the rotation. For many years it was considered impossible to use double-acting engines for high-speed work, owing to the severity of the shocks at each reversal of the reciprocating motion—that is, at the end of each stroke. Whereas, in the single-acting engine, instead of the alternate push and pull on the crank pin and other parts, the forces can be made to act always in the same direction, and the possibility of severe knocking is thus eliminated.

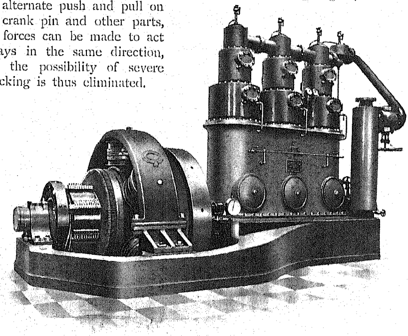
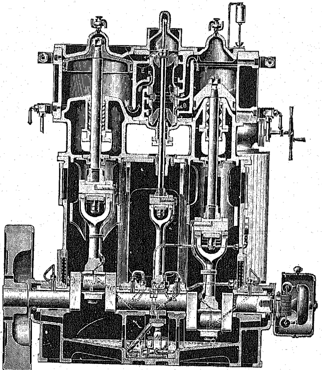


Fig. 491.—Willans Compound Three-crank Engine with Direct-coupled Continuous-current Generator

THE WILLANS AND ROBINSON CENTRAL-VALVE ENGINE.—Until recently this single-acting engine was greatly favoured for the direct driving of generators, on account of the quietness and uniformity of the motion and of the economical results obtained, but it is now rarely installed, for reasons which will be explained later. The engines were made either simple, compound, or triple, and with one, two, three, or more cranks, according to the power and the uniformity of drive required. In the simple engine one cylinder was arranged over each crank, and in the compound engine a high-pressure cylinder was placed in tandem over each low-pressure one. Thus an engine of large power having several cranks might be considered as consisting of a corresponding number of distinct tandem engines combined in one frame. To prevent any possible

reversal of the thrust on the crank pin an air buffer was provided in line with each set of steam cylinders, as shown in fig. 490. It should be noted that the work expended in compressing the air is given out again on the next stroke, so that there is practically no loss of power. Probably the most characteristic feature is the central arrangement of the valves in the hollow piston rod, which is pierced with suitable steam ports, and is common to each line of cylinders. A general view of a Willans compound three-crank engine, coupled direct to a continuous-current generator, is shown in fig. 491.

THE BELLISS AND MORCOM DOUBLE-ACTING, SELF-LUBRICATING ENGINE.—Until the introduction by Belliss and Morcom of the system of forced lubrication, the double-acting engine could not compete at high speeds with the single-acting type, so far as silent running was concerned, owing to the severe knocking which takes place in the former case each time the driving force changes from push to pull. If, for example, the big end of the connecting rod coupled to the crank pin be considered, it will be seen that the top and bottom halves of the bush alternately transmit the driving force, and that while the one half is in close contact with the crank pin, the other half is not necessarily so, but may be separated by a space the thickness of which depends upon the running conditions. To obviate the destructive knocking and wear which results from these conditions, Messrs. Belliss and Morcom provide a special valveless pump, which forces oil at a pressure of from 10 to 20 lbs. into the working parts, which are thus prevented by the cushion of oil under pressure from coming into actual contact.



Front Section

Fig. 492.—The Belliss & Morcom Double-acting Engine (front section)

A section of the engine is given in fig. 492, from which it will be seen that the cylinders are arranged side by side, and that the exhaust steam from the high-pressure engine passes directly to the low-pressure cylinder, the cranks being set 180 degrees apart. One common piston valve serves

for both cylinders, and the number of working parts is thus considerably reduced.

CHAPTER V

STEAM TURBINES

DEVELOPMENT OF STEAM TURBINES.—So far as the principles of reaction and impulse, upon which the motion of the steam turbine depends, are concerned, the earliest recorded examples are the Reaction Wheel invented by Hero of Alexandria 130 years before the Christian era and the Impulse Wheel of Giovanni Branca, which dates from 1628. The practical introduction of the steam turbine may be considered as dating from 1884, when the Hon. C. A. Parsons, to whom the later development of the system is largely due, obtained his first patent for an impulse-reaction turbine. In 1888 Dr. G. de Laval devised a single-wheel impulse arrangement which has been extensively applied with great success, and in America the development of the multicellular type is due to Mr. Curtis, whose original patent is dated 1896. There are now other successful makes of turbines, such as the Rateau and Zoelly, differing from the Laval or Curtis impulse types more in arrangement and detail than in principle. But the Parsons turbine is the only important example of the mixed or impulse-reaction type.

STEAM TURBINE *v.* RECIPROCATING ENGINE.—From the point of view of steam economy, the steam turbine cannot at the present time be said to greatly surpass the best reciprocating engines, especially for comparatively low powers, and the great development that has taken place is due more to several indirect advantages which determine the economy of the plant as a whole. In the first place, owing to the relatively high speed, the size of the turbine and the weight of its foundations in the case of a land station are small in comparison with an equivalent reciprocating plant, and the capital cost of the power house is accordingly much less, as will be evident from fig. 493, which shows the comparative sizes of a turbine and a reciprocating engine plant of equal power.

Less oil is consumed, and the engine-room staff is generally smaller. These advantages represent a large saving in the capital cost of a new installation and some reduction of the working expenses, apart from any actual economy of steam which may result from the superior thermal conditions of working. In the reciprocating engine the live high-temperature steam enters a cylinder which immediately before has contained steam at the lower temperature of the exhaust, and which may still contain some moisture; whereas in the steam turbine the temperature falls uniformly from the high-pressure end to the low, and the steam is never subjected to a sudden change of temperature. It is also possible to carry the expansion to a further degree in the turbine, because the diameters of the low-pressure cylinders of reciprocating engines are limited by practical

considerations. This important feature has recently led to the introduction of turbines as auxiliaries to reciprocating engines, the exhaust from which is led through heat accumulators to the turbines, where it is expanded more completely before being rejected to the condensers. At sea the results obtained from turbine installations have not in all cases proved entirely satisfactory. To a large extent the trouble arises from the high speed of rotation, which depends upon the velocity of the steam, and from

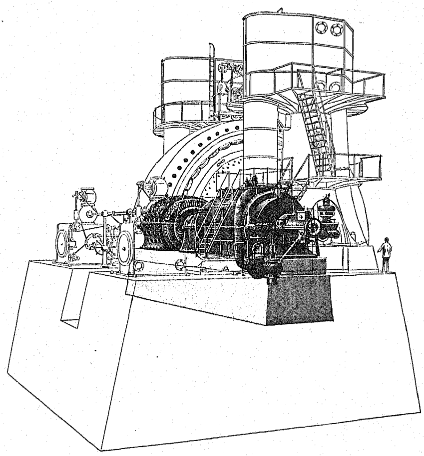


Fig. 493.—Comparative Sizes of a Turbine and a Reciprocating Engine Plant of Equal Powers

lack of knowledge as to the best size and form of propeller to suit the conditions of running. Propellers for turbine-driven boats are at present determined as much by trial-and-error methods as by design. To reduce the speed of rotation without affecting the peripheral speed, which for maximum economy must be approximately half the speed of the steam at the particular stage, the number of expansion stages and the diameter of the turbine rotor are increased as far as the questions of weight and size permit, and in many marine installations there is at the present time very little saving in these respects.

PRINCIPLE OF THE STEAM TURBINE.—As in the case of the water turbine, the energy of motion of the working substance is abstracted in the passages of the moving wheel, which is thus caused to rotate; but since the physical properties of water and steam are very different there is but little further resemblance between the two systems. Water is practically an incompressible fluid of considerable density, whereas steam is an elastic gas which expands indefinitely as the pressure diminishes, and which falls in temperature when work is developed in the operation.

If steam be expanded in a conical nozzle of the section shown in fig. 494, its pressure falls while the velocity increases; but although the total thermal energy remains unaltered, provided no work is done, a change takes place in the character of the energy, which becomes more kinetic.

In the DE LAVAL TURBINE the steam is expanded in one or more conical nozzles down to the pressure of the exhaust, and all its available

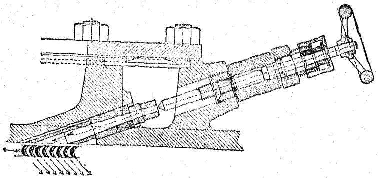


Fig. 494.—Laval Conical Expansion Nozzle

energy becomes kinetic during the one stage. The expanded high-velocity steam then impinges upon buckets or vanes on the periphery of the rotor, and in its passage through them the direction of the motion of the steam is altered and thus its energy of motion is communicated directly to the wheel. For maximum efficiency it is necessary that the speed of the buckets should be about half the speed of the steam; but in practice, owing to the great velocity of high-pressure steam when expanded down to a pressure of 2 to 3 lb., a smaller and safer speed than half is generally adopted. Thus, if the initial pressure be 100 lb., the velocity of the steam, when expanded in a nozzle down to a good vacuum, would be over 4000 ft. per second, and the wheel buckets should for maximum efficiency have a velocity of 2000 ft. per second, but an actual velocity of 1200 ft. per second is rarely exceeded.

One of the essential features of such single-stage wheels is the long flexible shaft, which yields sufficiently to allow the quickly revolving wheel to rotate about its true dynamical axis, which, on account of small defects of balance, may not coincide with the mechanical axis.

Fig. 495 shows the general arrangement of a 225-h.p. Laval turbine in which the high speed of rotation is reduced by means of helical gears, the gear box being shown between the turbine on the right and the twin

dynamo on the left. For most purposes some such gearing is necessary, as questions of safety impose a limit upon the diameter of the turbine wheel itself.

Turbines of the Laval type belong to the impulse or action class, and are distinguished by the fact that the steam does not expand during

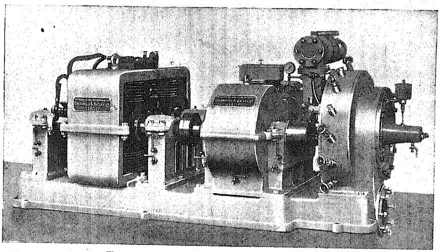


Fig. 495.—225-h.p. Laval Steam Turbine and Twin Dynamo

its course through the wheel passages, the sectional areas of which are constant. As a result there is no difference of pressure across the wheel, and therefore the working clearances may be made large, since there is no tendency to steam leakage. The one great objection to the single-wheel system is the unavoidable quick speed of rotation.

The IMPULSE-REACTION OR MIXED TURBINE, to which the Parsons type belongs, makes use of the principles of both reaction and impulse, as the name implies. In such cases the expansion is divided into a number of stages, over each of which there is a certain fall of pressure. By dividing up the expansion in this way the peripheral speed is correspondingly reduced, and when the stages are increased in number to fifty, as in the Parsons turbine, the speed of rotation is reduced sufficiently for most practical purposes without unduly increasing the diameter of the rotor.

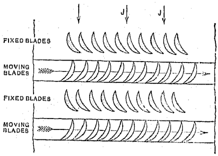


Fig. 496.—Arrangement of Turbine Fixed and Moving Vanes

Each stage comprises two rings of vanes or buckets—one set fixed to the turbine casing, and the other to a common wheel or rotor. If these sets of vanes could be partially exposed, the appearance presented would be as shown in fig. 496.

Horizontal arrows mark the direction of rotation, and the small vertical ones JJ indicate the flow of the steam, which actually takes a somewhat spiral course from one end of the rotor to the other. Steam enters the first ring of fixed blades, and in its passage through them suffers only a change of direction. There is practically no change of pressure, as throughout them the section normal to the direction of flow is constant. The exit angle of the fixed vanes is such that the steam is directed upon the moving vanes so as to enter them with the least possible shock, and in its passage through the latter the steam not only acts by impulse, as in the Laval type, but it is also allowed to expand and thus to react upon the vanes. A second set of fixed vanes again changes the direction of the flow and redirects the steam upon the next set of moving buckets. As the steam

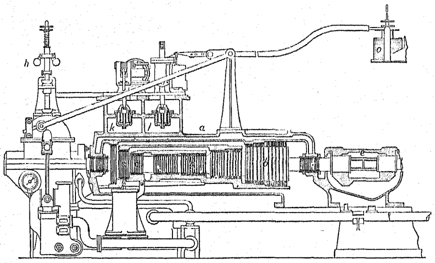


Fig. 497.—Early Example of the Parsons Turbine

expands it is necessary to correspondingly increase the capacities of the succeeding elements, and theoretically the increase should correspond with the curve of adiabatic expansion which is approximately followed; but for practical reasons the stages are grouped as shown in the section, fig. 497, which is an example of an early Parsons turbine designed for the direct driving of electrical generators. The turbine is divided into three portions *b*, *b*, *b*—a high-pressure, an intermediate, and a low-pressure turbine, the diameters of which are made each larger than the previous one. It will also be seen that the heights of the vanes are increased in sets, the high and intermediate groups being divided into two and the low into three portions to suit the gradually increasing volume of the steam. The rings of fixed guides are shown attached to the casing between the successive rings of moving vanes attached to the rotor, and, owing to the difference of pressure over each stage, it is essential that the clearances should be made as small as possible in order to avoid serious loss by leakage. On the end of the rotor, at the left hand in the illustration, will be seen three sets of

dummy pistons C, the mean areas of which are respectively equal to the effective areas of the high-, intermediate-, and low-pressure turbine vanes, and on the upper side will be seen the passages which place these pistons

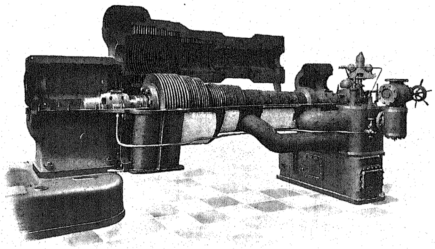


Fig. 498.—1000-kw. Parsons-Willans Steam Turbine, with upper casing hinged back to expose the rotor

in communication with the steam spaces of the corresponding turbine sections. This is done in order to balance the end thrust due to the reaction of the steam, and thus to dispense with a separate thrust block. In the particular example given, two steam-controlling valves *k* and *l* are

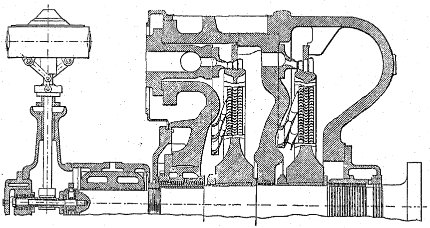


Fig. 499.—Radial Section of the Curtis Steam Turbine

indicated. One of these is controlled by a centrifugal governor *h* and acts when the speed varies considerably, while the other is operated by means of a solenoid *o* which acts when the voltage of the generator fluctuates. Fig. 498 is an illustration of a 1000-kw. Parsons-Willans turbine with the

upper half of the casing hinged back to expose the rotor, and the Plate shows a marine low-pressure turbine with the reverse turbine combined in the same case.

Turbines of the CURTIS, RATEAU, AND ZOELLY TYPES resemble the Laval in that the steam does not expand in the moving vanes; but

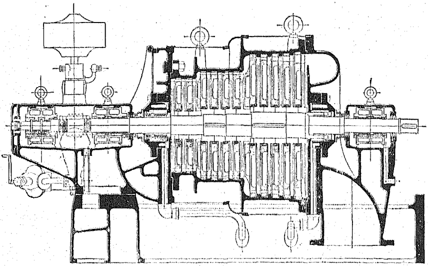


Fig. 500.—Sectional Elevation of Rateau Steam Turbine

they differ in having several sets of stages, and are equivalent to a series of Laval wheels, each of which rotates at a more moderate speed. Fig. 499 is a radial section showing the essential features of the Curtis turbine as manufactured by the Allgemeine Electricitäts-Gesellschaft of Berlin, and it will be seen that the expanding nozzles are arranged

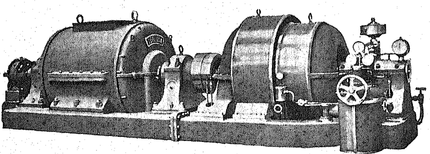
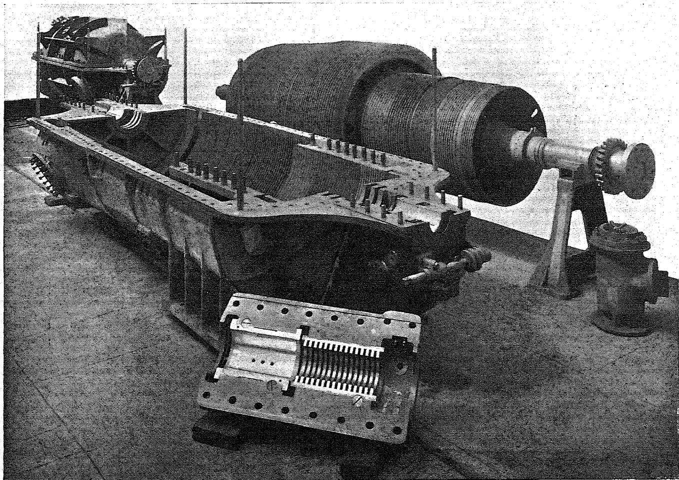


Fig. 501.—1500-kw. Rateau-Oerlikon Steam Turbine

around the peripheries of the fixed wheels placed between the sets of rotating vanes. In the case of the first wheel the nozzles occupy only a portion of the periphery, but in the succeeding ones the number of passages is increased to suit the greater volume of the expanded steam. High-pressure steam is admitted to the first set of nozzles, in which it is partially expanded before its admission to the first set of moving buckets.



(63)

MARINE LOW-PRESSURE PARSONS TURBINE, WITH THE REVERSE TURBINE IN THE SAME CASING

It should be noted that in this particular example there are two rings of vanes on the first wheel, separated by a set of fixed guides which merely change the direction of flow of the steam. In the moving wheel the steam velocity falls as its kinetic energy is absorbed, and it is necessary to again raise the velocity by further expanding it in the next set of nozzles before its admission to the second moving wheel. This operation is repeated in the succeeding stages, until at the last the pressure of the steam equals that of the condenser when all the available energy has been abstracted. A section of the Rateau turbine, which differs only in questions of arrangement, is given in fig. 500, and fig. 501 shows the external appearance of a 1500-kw. turbo-generator set as manufactured by the Oerlikon Maschinenfabrik of Switzerland.

CHAPTER VI

GAS PRODUCERS—INTERNAL-COMBUSTION ENGINES—GAS ENGINES—OIL ENGINES

GAS PRODUCERS

PRODUCER GAS.—Internal-combustion engines, which will be described later, are now being extensively used, not only for the production of small powers, but also in competition with the largest steam-engine plants. This development has necessitated the introduction of suitable plant for producing the gaseous fuel required, and there are now many types of apparatus which produce such gas from the various qualities of coal in common use, but for gas-engine work it is preferable where possible to use anthracite, to avoid the difficulties that arise in the complete extraction of objectionable tar. Producer gas is also greatly used for other purposes, such as the firing of metallurgical furnaces, and in such cases the complete extraction of the tars is of less importance so far as the actual consumption of the gas is concerned, but in large plants, exceeding 3000 h.p., it is profitable to extract the by-products, of which, especially in the case of the ammonia, the market value is considerable. For small engines, of less than 20 h.p., ordinary illuminating gas drawn from the town mains is generally used, as the actual cost of the fuel is in such cases a minor charge when the convenience of the arrangement is considered. Small engines of this kind are very extensively used, and more especially in town areas, where the installation of a steam boiler is often prohibited.

Illuminating gas is produced by the distillation of suitable coal in closed retorts, and it consists largely of hydrogen and such hydro-carbons as marsh gas, CH_4, which have high calorific values. For illuminating purposes it is necessary to extract very thoroughly the impurities, and more especially the tars, which otherwise would accumulate in the mains, where their removal would be both difficult and costly. The price of

illuminating gas is therefore considerable, and for large gas engines a cheaper fuel of the nature of producer gas is essential to economy.

Producer gas is formed by the combustion of carbon, and in its simplest form consists of carbon monoxide, CO, which results from the oxidation of the incandescent carbon in presence of an excess of the fuel. When air is passed through a layer of carbonaceous fuel the carbon is consumed, provided the temperature is sufficiently high, and carbon dioxide, CO_2, is formed. A certain quantity of heat also becomes sensible, and maintains the temperature of the fire. As the CO_2 passes through the hot fuel it combines with more carbon and forms the highly

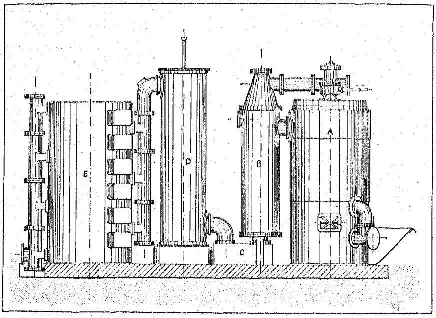


Fig. 502.—Gas-producer Plant (pressure type)

inflammable gas CO, carbon monoxide; but the heat evolved in the production of CO is less than in the case of CO_2, and about 30 per cent of the total heat becomes sensible in the production of CO, so that theoretically the maximum heat efficiency of the gas might be considered as 70 per cent. In reality the efficiency greatly exceeds this, as the liberated heat is utilized in other stages of the process.

Water Gas.—Gas produced in the above-described way is largely diluted with the nitrogen carried in by the air, and as nitrogen is not combustible, it only serves to carry away a portion of the heat. It is therefore desirable to have some more suitable source of oxygen, free from the very inert substance nitrogen, such as water, which may be readily dissociated at the temperature of the producer fire into its components, hydrogen and oxygen. When steam is passed instead of air into the incandescent carbon the liberated oxygen combines with the

carbon, as already explained, while the liberated hydrogen, which has a very high calorific value, passes away with the C O to the engine or the gasometer. Considerable heat is, however, absorbed in the splitting up of the steam, and as a result the temperature of the fire becomes seriously reduced when the steam supply exceeds a certain amount. It is therefore necessary to make the action intermittent by blowing air for a time, during which producer gas is evolved, and then blowing steam until the fire becomes affected, when the temperature is again raised by blowing air. This system is generally known as the water-gas process, and in practice it is essentially an intermittent one, producer gas and water gas being alternately evolved. In producer plants, which are now commonly used for a great variety of industrial purposes as well as for the driving of engines, the action is made continuous by so limiting the supply of the steam that the temperature does not fall. In reality, therefore, producer gas contains a certain proportion of water gas, which lowers the proportion of inert nitrogen by introducing in its place hydrogen, having a greater calorific value than any of the other constituents. Anthracite and coke are generally not so readily obtainable, and are more costly than the commoner classes of bituminous coals, and many endeavours have been made, with only partial success, to design a type of producer which would successfully burn these fuels. When bituminous coals are used, the volatile hydrocarbons help very considerably to increase the calorific value of the resulting gas.

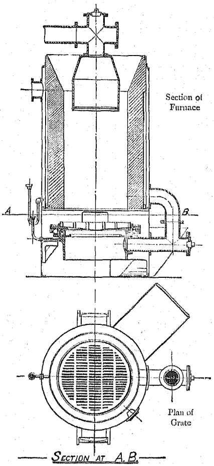


Fig. 503

PRODUCER PLANTS. — Producer plants for gas-engine purposes may be classified under two groups, according to the pressure maintained in the system. In the pressure type the gas is generated under a pressure higher than that of the atmosphere, and as C O is a very poisonous gas it is essential for safety to prevent all outward leakage. In the second arrangement the pressure is less than atmospheric, and leakage of air inwards can only result. There are other features of this latter system, which will be dealt with later.

In fig. 502 an outside view of a pressure plant is illustrated, and a section

of the furnace in side elevation, with a plan of the grate, is shown in fig. 503. Around the furnace, A, figs. 502 and 503, there is provided an air space, in which the supply of air and the water vapour which it has picked up in the saturator B (fig. 502) are heated before they pass into the chamber beneath the grate, and thence through the incandescent fuel. As the gases are produced they escape through the pipe at the top of the furnace to the saturator, where their heat is utilized in producing the steam

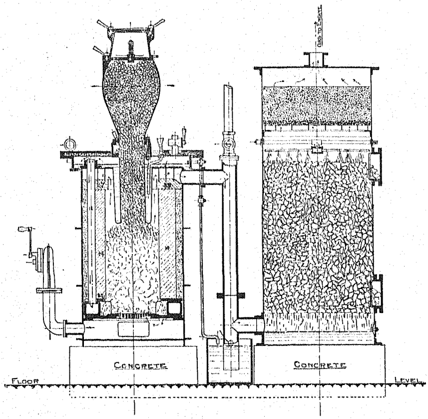
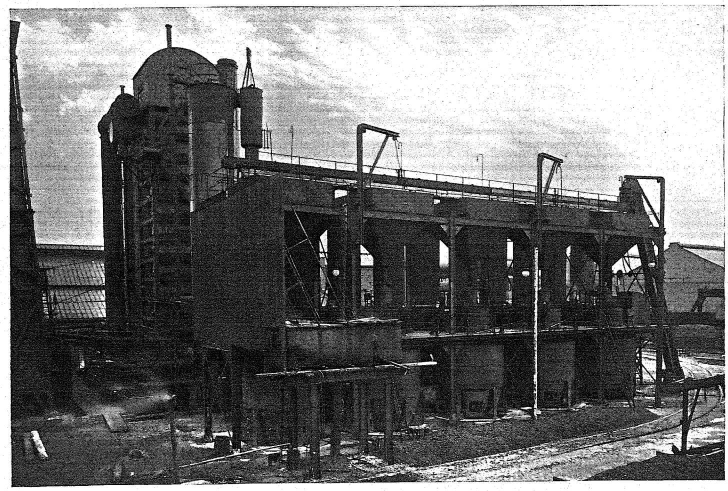


Fig. 504.—Suction Gas Plant (sectional elevation)

consumed in the furnace. From the saturator the partially cooled gases pass away to the gasometer through the cleaning apparatus, which consists of coke and sawdust scrubbers D and E. In many cases it is not necessary to have a gasometer, provided the gas is drawn from the plant under the required pressure.

SUCTION GAS PLANTS.—Suction gas plants are particularly adapted for use with gas engines, and it is the suction of the engine that maintains the action of the furnace. At each suction stroke the gas required for the explosion is sucked into the cylinder from the producer, and during the interval of the succeeding compression, explosion, and scavenging strokes a fresh quantity of gas is produced in readiness for the next



(64)

MOND GAS PLANT OF 8000 APPROXIMATE EQUIVALENT H.P. WITH AMMONIA RECOVERY INSTALLATION

MANUFACTURED AND ERECTED BY THE POWER-GAS CORPORATION, LIMITED

suction stroke. There is at no time a pressure equal to that of the atmosphere, and therefore the danger of objectionable leakage is avoided. In addition to this advantage the arrangement is very economical, as the production of gas varies with the demands of the engine. When the engine is running under full load the suction keeps the furnace working briskly, but as the load decreases the action becomes less vigorous, and a smaller quantity of fuel is consumed. There is a danger that, after a prolonged quiet period, the producer may not be able for a time to meet a sudden increase in the demand, and trouble is sometimes experienced on this account; but the many difficulties are being overcome, and there is little doubt that the application of suction plants will steadily increase. A sectional elevation of a common type of suction plant is given in fig. 504. The fuel is fed through the feeder at the top into the gas-tight hopper, from which it descends to the working level of the furnace. As the gases are evolved they escape through a series of concentric baffles into the scrubbers, where they are cleansed before their admission to the gasometer, where one is provided, or direct to the engine. In its passage through the concentric baffles some of the sensible heat of the gas is imparted to a supply of water which is circulated over the surfaces, and the steam thus generated is fed through the superheater space around the furnace into the fire grate, along with the secondary air supply, which is first saturated with moisture in the steam raiser. To start the producer, or to increase the action when required, a hand-starting fan is provided, and in this way a supply of air, called the primary supply, can be forced under the fire grate.

BY-PRODUCT RECOVERY PLANT.—When the quantity of gas required is great, as, for example, in installations exceeding 3000 h.p., a considerable saving may be effected by installing plant for the recovery of the ammonia resulting from the combination of the fixed nitrogen of the fuel and a portion of the hydrogen. To the late Dr. Ludwig Mond was largely due the credit of having made the production of uniform qualities of gas possible on a large scale and at a sufficiently cheap rate.

The Plate shows a Mond gas and ammonia recovery plant of approximately 8000 h.p. built and installed by the Power-Gas Corporation.

INTERNAL-COMBUSTION ENGINES

It has long been recognized that the system of generating power directly by burning the fuel in the cylinder of an engine is theoretically much more efficient than the steam-engine method which has been so greatly developed. A good steam engine is able to transform usefully about 15 per cent of the heat supplied to it, and the theoretical maximum efficiency is about 30 per cent. At the present day the gas engine, so far as thermal efficiency is concerned, is generally accepted as being already twice as good as a steam engine of equal power, and there is no rigid limit to the efficiency. According to figures given by Mr. J. Emerson Dowson in his work upon producer gas, the approximate efficiency of a good gas engine may be taken as being 28 per cent, and this figure

does not differ much with the size of the engine. Of the 72 per cent that is lost it is estimated that 30 per cent is dissipated in cooling the cylinder, and that the remainder largely passes away in the exhaust gases. Attempts have recently been made to utilize the heat of the waste gases, which amounts to about 40 per cent of the whole quantity, but so far the practical results obtained have not been great. For larger powers, up to about 300 h.p., it is necessary to use a cheaper class of gas, such as is obtained from the present types of anthracite suction gas plants; but for still larger powers the use of cheaper bituminous fuel is necessary to enable the large gas engine to compete with steam. Difficulty is, however, frequently experienced in the working of such bituminous plants and in the utilization of the gas, owing to the presence of unextracted tar. This question of a suitable producer is one of several problems that must be solved before the large gas engine can be fully relied upon for constancy and regularity of working. There is also the difficulty arising from the pressure in the cylinder, which may amount to from 400 to 500 lb. per square inch, and which may necessitate, in the case of large-diameter cylinders, walls of 3 in. in thickness to withstand the stresses due to the explosion. This excessive thickness of wall prevents the efficient cooling of the internal working surface, and owing to the great difference of temperature between the inside and the outside, the metal is subjected to severe expansion stresses, which have too frequently resulted in the cracking of the cylinder walls. In small engines, or in large engines having a number of small-diameter cylinders, the same trouble is not experienced.

Oil engines resemble gas engines in many respects, but they involve the use of certain additional organs in which the oil vapour is produced. A simple carburettor therefore takes the place of the large producer plant. But oil is an expensive fuel, and such engines are only used under special circumstances where suitable gas is not available.

An enormous industrial field has within recent years been opened up by the development of motors in which light-oil vapours are consumed. For motor-car purposes the petrol motor is almost universally used, but there is no doubt that cheaper spirits will in the future be employed with success. Alcohol, which may be extracted from vegetable substances, and is therefore unlimited in quantity, has been proposed as a suitable substitute, but in Britain there are legislative difficulties which must be removed before any progress in this direction can be made. Alcohol has only about half the calorific value of petrol, but its flashpoint is over 60° C., compared with 10° C. in the case of petrol, and it may therefore be compressed to a much higher pressure in the cylinder. The efficiency of an internal-combustion engine is largely determined by the extent to which the charge can be compressed before its explosion.

GAS ENGINES

DEVELOPMENT OF THE GAS ENGINE.—To Lenoir is due the credit of having practically introduced the gas engine, but the engine was in design merely an adaptation of the simplest type of steam engine then in

common use. Coal gas and air were drawn into the cylinder during a portion of the stroke, and then the admission valve was closed and the charge ignited by an electric spark. As a result of the explosion the piston was driven forward, and the energy imparted to the flywheel was sufficient to maintain the motion during the succeeding stroke, while the burnt gases were being expelled, and also to suck in a fresh charge for the next explosion. Messrs. Otto and Langen, to whom the early development of the practical gas engine is largely due, introduced in 1867 a free-piston engine (fig. 505) which gave very remarkable results, and which was manufactured in large quantities. On the explosion of the mixture the piston was driven upwards at a high velocity, but by means of a clutch arrangement no driving force was communicated to the shaft and flywheels. On the downward stroke the clutch within the pinion gripped the shaft, and thus the motion was communicated to the flywheels. A slide valve operated from the engine shaft was used for the admission, ignition, and exhaust, the firing being effected by an external flame which was brought into contact with the explosive charge by the movement of the slide. Engines of this kind are generally referred to as belonging to the "free-piston" type.

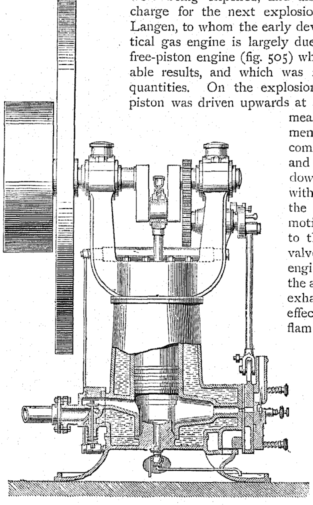


Fig. 505.—The Otto & Langen Gas Engine

The Otto Cycle.—In these early engines expansion of the gases took place during the latter portion only of the stroke, and although M. Beau de Rochas in a French patent of 1862 proposed a "four-stroke" cycle, in which the gases were compressed before their explosion, it was not until 1876 that the scheme was practically applied by Dr. Otto, who appears to have independently invented it. This four-stroke cycle is now known as the Otto cycle, and the successful introduction of internal-combustion engines may be dated from that time. In the Otto cycle there is one explosion and working

stroke in two revolutions of the crank or four successive strokes of the piston.

The strokes are as follows:—

1. *Suction Stroke.*—The explosive mixture of gas and air is drawn into the cylinder throughout the stroke.

2. *Compression Stroke.*—The charge is compressed into a comparatively

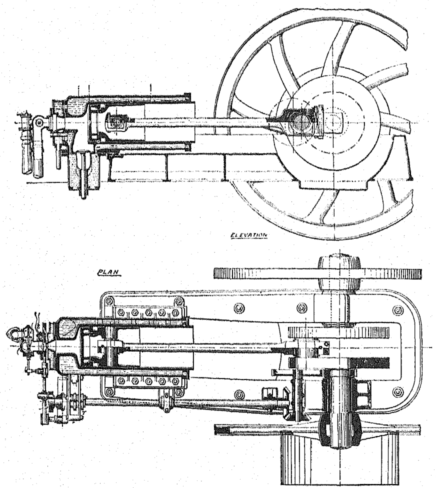


Fig. 506.—Sectional Elevation and Plan of a 100-h.p. "Simplex" Gas Engine

large clearance space at the end of the cylinder, the amount of the compression being dependent upon the nature of the mixture, which must not be compressed so far as to ignite prematurely.

3. *Working Stroke.*—At the beginning of the stroke the gases are ignited, and the explosion drives the piston to the end of the cylinder.

4. *Exhaust or Scavenging Stroke*, during which the burnt gases are expelled. In the following stroke the cycle is recommenced by the suction of the next charge.

THE CLERK CYCLE.—Gas engines are also constructed to work on a "two-stroke" or "Clerk" cycle, in which there is an explosion during each revolution of the crank; but it cannot be said that the results obtained from the large engines built upon this system have been wholly satisfactory.

A separate pump is used for drawing in the charge of air and gas in the correct proportions, and the pump then feeds the mixture into the working cylinder at the moment when the exhaust valves are opened. As the mixture enters the cylinder it expels the waste products of the previous charge through the exhaust valve, and one of the difficulties lies in preventing some of the mixture from also escaping.

WORKING OF THE ENGINE.—An illustration of a common type of engine for small powers is given in section (fig. 506) to show the general

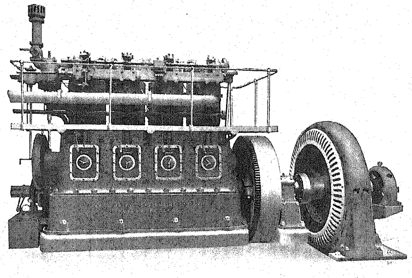
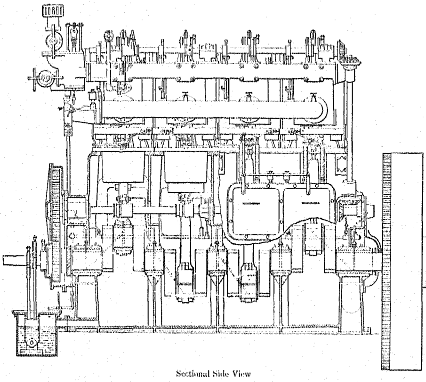


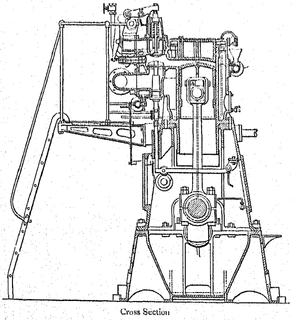
Fig. 507.—Campbell Four-cylinder Gas Engine with Direct-coupled Electrical Generator

arrangement of the parts. It will be seen that the cylinder walls are jacketed with water, which circulates naturally through them from a series of water-cooling tanks placed at a higher level, the flow being determined by the differences in the temperature. As is generally the case, the engine is of the single-acting type, and advantage is taken of this feature by dispensing with a piston rod and using a bucket piston, which reduces the overall length very considerably. At the same time the use of a bucket piston helps to cool the internal working surfaces. The various valves are operated from a common shaft so geared as to rotate at half the speed of the crank; for this reason it is commonly called the "half-time" or "half-speed" shaft. Upon the shaft are fixed cams which act upon the spindles of the valves and open them in rotation and at the correct moments. Firing of the mixture may be effected either by opening a communication between the compressed charge and the exterior of an iron ignition tube heated to redness by means of an internal flame, or it may be effected electrically, in



Sectional Side View

Fig. 508.—Campbell Vertical Four-cylinder Internal-combustion Engine



Cross Section

Fig. 509.—Campbell Vertical Four-cylinder Internal-combustion Engine

which case a battery or magneto is provided with suitable arrangements for producing the spark in the explosive chamber itself.

A general outside view of a Campbell four-cylinder gas engine coupled directly to an electrical generator is shown in fig. 507. These engines are designed for the driving of generators, and are built in sizes of from 100 to 750 b.h.p. A part sectional side view and a cross sectional view are given in figs. 508 and 509. Each cylinder has an independent set of valves

and ignition gear, and the engine works on the Otto four-stroke cycle.

METHODS OF GOVERNING.—There are three common systems of governing the speed to suit variations of the load.

1. By governing the quality of the explosive mixture.
2. By governing the quantity.
3. By the "hit-and-miss" system.

In the quality method the proportions of the air and gas in the mixture are varied without altering the actual volume of the charge. There are, however, limits beyond which the gas cannot be diluted without fear of making the gas of too poor a quality to ignite. It is very customary to

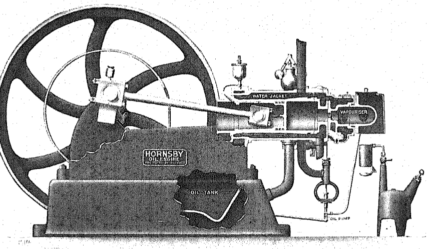


Fig. 510.—Hornsby Oil Engine (part sectional elevation)

fit an additional governor of the hit-and-miss type, which comes into action when the loads falls below one-half.

Under the quantity system the proportions of the air and gas in the mixture are kept constant, so that the possibility of missfires at low loads is avoided. Only the quantity of the mixture is varied, and, as before, there is regularly one explosion per cycle. Theoretically this arrangement is not good, as the compression is not then constant; but, on the other hand, the combustion is complete, and the ignition is certain at all loads, both of which features are of importance in practice.

In the hit-and-miss system, which is the most economical of the several arrangements, a strut from the governor is suspended between the valve spindle and the operating lever head in such a way that when the strut is raised by the action of the governor, as the speed rises, the lever head misses the strut and fails to open the admission valve. As the load falls,

and therefore as the speed of the engine rises, one or more consecutive charges are omitted until the speed again falls to the normal. With this arrangement it is difficult to ensure uniformity of the speed, which during the idle strokes has to be maintained by the momentum of the flywheel. There is a greater tendency now to abandon the hit-and-miss system on this account, and more especially as the demands for close regulation are steadily increasing.

OIL ENGINES

Oil engines are used for smaller powers when the conditions are favourable, but within recent years progress has been made in the introduction of

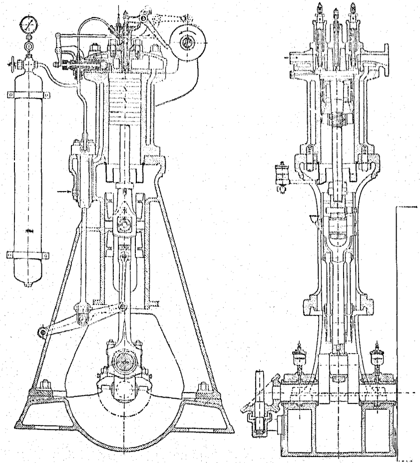


Fig. 511.—Sectional Side and Front Elevations of Diesel Engine

larger engines capable of consuming cruder and therefore cheaper classes of oils. In engines of this class the oil is broken up into minute globules and intimately mixed with air by means of a carburettor, of which there are many forms. In general the oil is scattered by a jet of air and carried

over into the cylinder, where the mixture is compressed as in the case of the gas engine, but to a lesser degree. When ignition takes place, the oil burns rather than explodes, and the initial pressures are not so high as when gas is burned. A part section of the Hornsby oil engine is given in

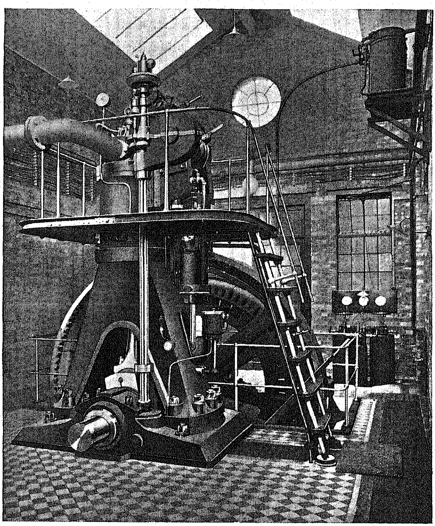


Fig. 512.—Diesel Engine with a Direct-coupled Generator

fig. 510, and the portable burner arrangement is shown at the right-hand end under the cylinder. It will be seen that, apart from certain details, there is little mechanical difference between oil and gas engines.

When the combustible mixture is compressed until the temperature rises to the point of ignition there is great danger of premature explosion, and the degree of compression is therefore limited.

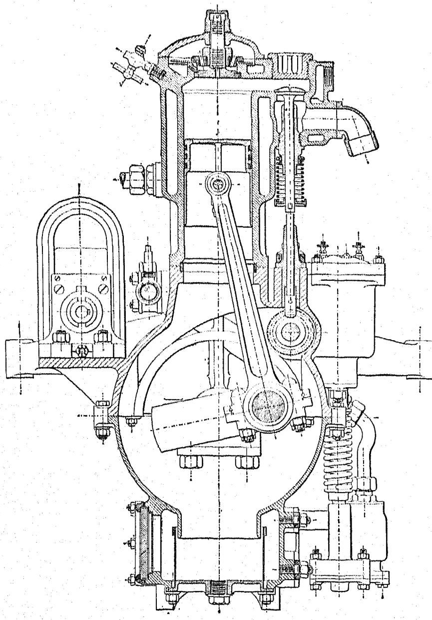


Fig. 513.—Cross Section of Dion-Bouton Two-cylinder Motor

Mr. Diesel has overcome this difficulty in the Diesel engine by compressing the air alone in the cylinder and then injecting the oil into it. The air is compressed to about 500 lb. per square inch, and as a result a temperature of about 1000° F., sufficient to ignite the fuel, is attained without the aid of any separate ignition arrangements. Petroleum is

then injected into this high-temperature air, and combustion at once takes place as the oil is admitted. Owing to the more gradual combustion as compared with the explosion of gas, there is at all times a less temperature difference, and the losses to the walls are therefore smaller. Sections of the Diesel engine are given in fig. 511, and an external view in fig. 512.

Carburetted-air engines have been developed to a high degree in connection chiefly with the motor-car industry, but they are now being used for many other important purposes on land and sea, and the introduction of these small high-powered engines has made possible the recent development of dirigible balloons and aeroplanes.

A section through one cylinder of a Dion two-cylinder motor is shown in fig. 513, and this example may be taken as typical of those applied to motor cars. It works upon the Otto cycle, and the fuel is a gaseous mixture of air and the vapour of such spirits and volatile oils as alcohol and petrol. Both the exhaust and the inlet valves are operated positively from a half-time shaft, which, as already explained, makes one revolution during two revolutions of the crank. Motors of this kind will be more fully dealt with later, in their application to the motor car.

CHAPTER VII

ELECTRICAL MACHINERY: DYNAMOS—MOTORS—TRANSFORMERS. ELECTRICAL POWER: PRODUCTION, TRANSMISSION, AND DISTRIBUTION—STORAGE BATTERIES

DYNAMOS

PRINCIPLES.—Three-quarters of a century have barely elapsed since Faraday discovered the phenomenon of electrical induction, which forms the basis of modern electrotechnics. It is certain that magnetism and electricity were both the subjects of discussion among the philosophers of a much earlier period, and the use of the magnetic needle is attributed by some to the Chinese of 120 A.D. So far as modern practice is concerned, the present state of development is the growth of only thirty years, and the most important advances have been made within a still shorter period. Considering the varied nature of electrical engineering, and the numerous kinds of machines employed, it will not be possible here to treat of the subject historically, or to enter into any theoretical consideration of the principles involved, beyond what is necessary to make the operation of the various machines understandable.

When the lines of magnetic force surrounding the poles of a magnet are cut by a loop of wire moved through them, a current is induced in the wire, and the flow continues in the closed circuit so long as the lines of

force are being cut. If the loop be held stationary relatively to the magnetic field, no flow of current takes place; but as soon as relative motion takes place, the current commences to flow with a strength which depends upon the rate at which the magnetic lines of force are cut. If the motion be reversed the flow of current will also be reversed, and there is a definite relationship between the various elements, which was first established by Oersted in 1820. There are three ways in which the voltage, that is, pressure, of the induced current may be made as great as is desired. The density of the magnetic flux, or the speed of rotation, or the number of loops in the coil may each be increased, so that in practice there is considerable latitude in the question of design.

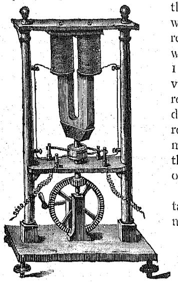


Fig. 514.—Early Pixii Dynamo

Early Dynamos.—From this elementary explanation the action of the first dynamo (fig. 514), introduced by Pixii in 1832, will be more readily understood. On the top of the frame is arranged the conductor coiled upon two bobbins in series. Underneath the bobbins is placed the permanent magnet, the poles of which may be caused to sweep past the coils in which the current is induced. As the magnet poles sweep past the bobbins the rate at which the field is cut by the coils will be a maximum for that particular speed, and the voltage will therefore reach its highest value, as shown at B in fig. 515. When the poles turn through 90 degrees they will lie across the plane of the coils, and the voltage of the induced current will be a minimum, as at C. As the rotation is further continued current will again increase, but its direction will be reversed, since the north pole of the magnet is now cutting the coils, which before were under the influence of the south pole. This is indicated in the diagram, which shows the variation of the current intensity during one revolution of the magnet. For many purposes it is necessary to have a current which does not change in direction. Thus, for example, it would be impossible to store such alternating current by means of accumulators, as the chemical effects produced by the flow in one direction would be immediately neutralized by the reversed flow. So far as the external circuit is con-

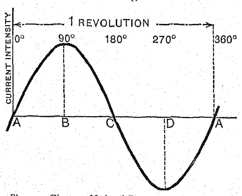


Fig. 515.—Diagram of Induced Current Intensity or Voltage in the Pixii Dynamo without a Commutator

cerned it is possible to make the current flow always in the one direction by changing over the connections to the coils at the moment when the current flow is reversed. Currents of this kind are said to be commuted, and the arrangement of contacts for effecting this result is called a commutator, one of which in its simplest form is shown upon the rotating spindle of the Pixii machine, fig. 514. In 1857 DR. WERNER SIEMENS introduced certain improvements both in principle and in design, and his arrangement is commonly in use at the present day with very slight essential modifications. An early Siemens machine is illustrated in fig. 516. Permanent magnets A are used as before for the production of

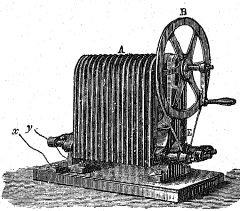


Fig. 516.—Early Siemens Dynamo or Magneto

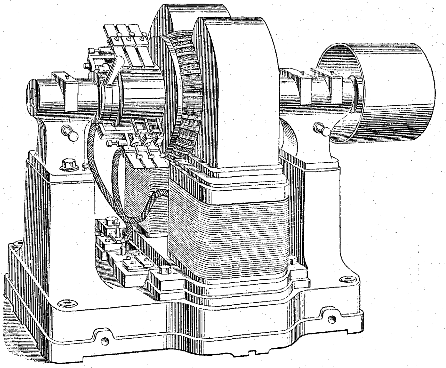


Fig. 517.—Two-pole, Continuous-current Dynamo

the magnetic field in which the armature coil E rotates, and to machines of this kind is given the name magneto. If the current produced by a simple

single-coil machine of this type were passed through a suitable electric lamp the light would rise and fall at each pulsation, and for many other purposes it is desirable to have a continuous current flowing in one direction. This is effected in modern dynamos by arranging a large number of coils around the armature in such a way that at any moment one or more is passing through its position of maximum current strength, and by providing a commutator the bars of which are connected in order to the various coils.

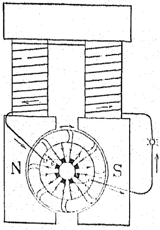


Fig. 518.—Dynamo with Electro-magnetic, Series-wound Field

A Modern Dynamo.—A simple continuous-current dynamo suitable for electric-lighting purposes is shown in fig. 517. At the sides are shown the field coils through which a portion of the current produced is passed in order to magnetize the poles that create the magnetic field, and the armature is shown in position between the poles. The armature is built up of laminations or stamped rings of soft iron strung upon the spindle and forced tightly together to prevent the humming sound which is otherwise produced. By dividing up the core in this way the formation of stray local currents is prevented and the efficiency is improved. Longitudinal slots are cut in the face of the armature core or, as it is called, carcass, and into these the coils are fitted. Each coil may consist of a number of turns of wire, or, when the current to be carried is con-

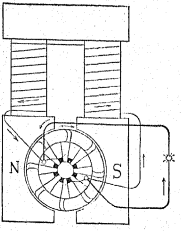


Fig. 519.—Shunt-wound Dynamo

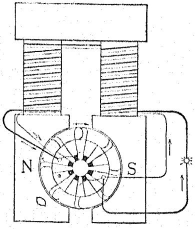


Fig. 520.—Compound-wound Dynamo

siderable, of copper bars, and in practice they are taped together and separately formed so that they may be readily inserted in the armature slots, and the ends connected in the case of a two-pole machine to diametrically opposite bars of the commutator. The currents generated by the arma-

ture are led away to the external circuit from the copper or carbon brushes which bear upon the commutator surface. A portion of the current also passes through the field coils, which may be either in series with the armature or in parallel, or partly in both series and parallel circuit.

WINDING OF FIELD COILS.—According to the winding adopted for the field coils dynamos are said to be series, or shunt, or compound wound, and the three methods of winding are shown diagrammatically in figs, 518, 519, and 520. In the case of the SERIES WINDING it will be seen that the whole of the current produced passes through the field coils,

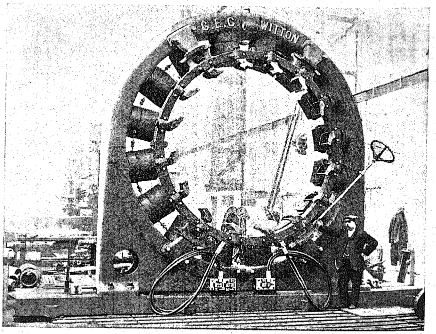


Fig. 521.—Field Magnets of 1000-kw., Continuous-current, Multipolar Dynamo

and that the greater the current flowing in the external circuit the greater is the strength of the magnetic field. When the external circuit is opened the flow ceases, and the field becomes practically zero. In the case of the SHUNT-WOUND MACHINE this is not so, for when the external circuit is opened there is still a path through the field coils, and therefore the strength of the field does not alter to the same extent as the external demands for current vary; that is, the voltage remains practically constant.

A series machine is best fitted for maintaining a constant current and a shunt machine for producing a constant voltage, but better "self-regulation" so far as voltage is concerned is obtained by combining the two systems in suitable proportions, in which case the dynamo is of the COMPOUND-WOUND TYPE.

MULTIPOLAR DYNAMOS.—For mechanical and electrical reasons dynamos are frequently built with two or more pairs of poles, a system

which permits of a high voltage being obtained without unduly increasing the armature wiring or the field density, or the speed of rotation. Each pair of consecutive poles of the multipolar machine acts as in the case of a single bipolar one, and the speed of rotation for a definite voltage when other factors remain unaltered is reduced in proportion to the number of pairs of poles. By increasing the number of poles the speed can be reduced sufficiently to permit of the generator being driven directly from the comparatively slow-speed engines installed in many power stations.

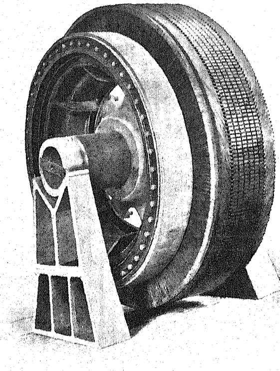


Fig. 522.—Armature of 1000-kw., Continuous-current Dynamo

An illustration of the magnetic portions of a large 1000-kw. (1340 mechanical h.p.), continuous-current, slow-speed generator by the General Electric Company of Birmingham is shown in fig. 521, and the armature is illustrated separately in fig. 522. It will be seen that there are eight pairs of poles and that the brush gear is multiplied in the same proportion. The brushes are connected in two corresponding sets, and are carried upon a ring capable of adjustment by means of the hand wheel, shown on the right, as the working conditions alter. This machine is of an exceptionally large diameter, and is designed for the comparatively low speed of 100 revolutions per minute and a voltage of 460, the power being used for both lighting and traction purposes. When a higher speed is permissible the number of poles does not generally exceed eight, and the machines are of

a much smaller diameter. A typical example of a six-pole, 350-kw., 460-volt, continuous-current generator is shown in fig. 523, directly coupled to a Belliss and Morcom high-speed engine, running at 375 revolutions per minute.

From many points of view the use of a commutator is undesirable. It is a costly part of the machine, and there are friction and electrical losses at the surface which cannot be entirely avoided. There is also difficulty, when the pressure exceeds 500 volts, in sufficiently insulating the adjoining coils of the armature without unduly increasing the size

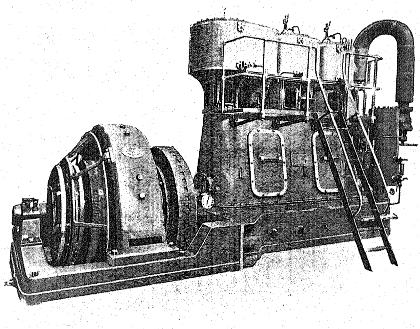


Fig. 523.—350-kw., Continuous-current Generator direct coupled to a Belliss & Morcom High-speed Engine

of the carcass, and for very high voltage, such as 5000 or 6000, the continuous-current type of machine is impracticable.

ALTERNATING-CURRENT GENERATORS.—Some reference has been already made to the simple or single-phase alternating currents induced in a coil when rotated so as to successively cut the north and south fields of a magnet, and the rise and fall of the current voltage during one period, or in this case revolution, has been illustrated in the diagram, fig. 515. Alternating currents are now extensively used for the driving of motors, and also for arc lighting when the number of cycles per second or the periodicity is sufficiently high to make the fluctuations unobservable; but it is for the production of high-voltage currents, suitable for transmission to motors or transformers at some distance, that alternators are chiefly employed. In fig. 524 is shown diagrammatically a single-phase, alternating-current generator connected to a single-phase

motor. Each consists of a stationary ring armature upon which the conductor is coiled and of a moving magnet, the fields of which cut the coils during each rotation. As the generator magnetic field approaches the coils a current of increasing intensity is induced, and as the field passes beyond

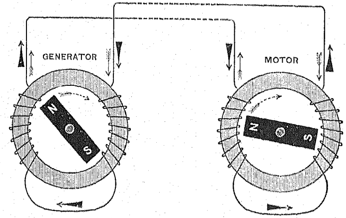


Fig. 524.—Single-phase Generator and Motor (diagrammatic arrangement)

them the intensity diminishes, until when the coil lies equally between them the induced current is zero. These currents flow through the coils of the motor armature, the core of which becomes alternately magnetized and demagnetized, and induced magnetic poles are formed intermittently at the portions of the rings between the coils. A single-phase motor of

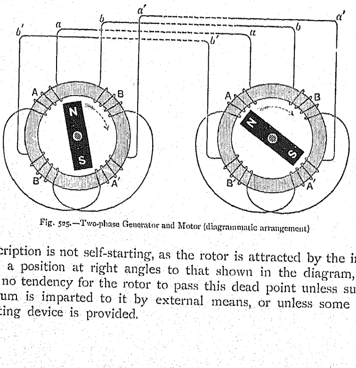


Fig. 525.—Two-phase Generator and Motor (diagrammatic arrangement)

this description is not self-starting, as the rotor is attracted by the induced poles to a position at right angles to that shown in the diagram, where there is no tendency for the rotor to pass this dead point unless sufficient momentum is imparted to it by external means, or unless some special self-starting device is provided.

Polyphase Machines.—By duplicating the system as shown in diagram, fig. 525, this difficulty of self-starting may be overcome, but the number of line wires between the generator and motor is doubled, although there is an actual economy of copper. It will be seen that the two circuits are independent and that one occupies a position 90 degrees in advance of the other. Considering first the generator, it will be evident that when the field magnet passes the coil A, the current pressure induced in coil A will be a maximum and in B a minimum. At a position midway between A and B there will be equal currents of intermediate value in both coils, and when the field passes coil B that coil will have its maximum

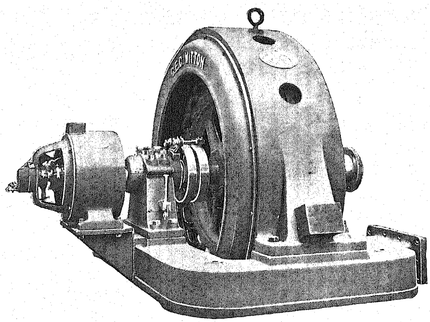


Fig. 526.—135-kw., Single-phase, Alternating-current Generator

current pressure and A its minimum. It will be seen that there is at every moment some current flowing in the motor, and that consequently the motor is more nearly self-starting. When there is full current in coils A of the motor, and none in B, the magnet poles are drawn into the position shown; and as the current in A falls and that in B grows, the position of the poles advances, until when equal currents flow through both circuits the field magnet is drawn into a position 45 degrees in advance of the former. When coil B is alone excited the field is still further advanced. Alternating currents of different phase flowing through the armature of a motor in the manner described produce as a result a rotating magnetic field, which forcibly drags round with it the rotor at a speed synchronous with that of the generator. Three-phase systems have, as the name implies, three windings, and when the number is still further increased the name polyphase is customarily used.

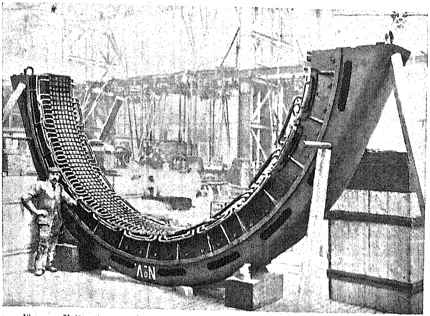


Fig. 527.—Half Stationary Armature Ring of a 1500-kw., Three-phase, Alternating-current Generator

Although a generator may be of the single-phase type, it may have a large number of pairs of coils grouped upon the armature, just as in the case of the continuous-current machine the number of poles was increased to suit a slow speed of revolution. By increasing the coils in this way the number of cycles, or, as it is called, the periodicity or frequency, is correspondingly increased. So far in considering these alternating-current machines it has been assumed that the magnetic field is produced by permanent magnets, but in practice it is necessary to use electromagnets, and therefore some source of continuous current is required for the excitation of the field. In

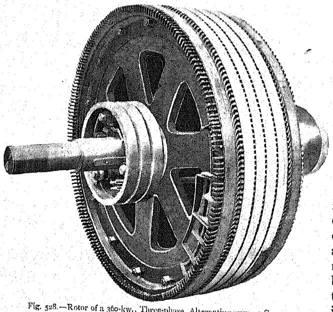


Fig. 528.—Rotor of a 360-kw., Three-phase, Alternating-current Generator

fig. 526 is shown a 135-kw., single-phase alternator arranged for direct coupling to a water turbine. On the extreme end of the shaft will be seen the small continuous dynamo which supplies the current for the excitation of the field coils carried upon the rotating part of the machine, and the slip rings and brushes through which the current is supplied to them are also shown upon the shaft. Alternators are sometimes built with the field portion stationary, but there is a great advantage in having the armature portion stationary, as the insulation can be better maintained, and there is less difficulty in arranging the connections. One-half of the stator or stationary armature portion of a 1500-kw., three-phase generator in course of erection is illustrated in fig. 527, and the arrangement of the three sets of coils in the slots of the laminated core is clearly indicated. The rotor of a 360-kw., three-phase set is also shown in fig. 528.

MOTORS

CONTINUOUS-CURRENT MOTORS.—A continuous-current generator may be run as a motor by merely providing a suitable type of starting switch, which first admits current to the field and then gradually to the armature coils as the speed increases, so as to avoid the danger of burning them. Motors are, however, generally made of a form different from that of the generator, to suit the conditions of working, which may require the working parts to be completely enclosed to protect them from dust and grit.

ALTERNATING-CURRENT MOTORS.—Alternating-current generators may also be run as motors, but their operation is not so simple as in the case of continuous-current motors; because in the first place their fields must be separately excited from a continuous-current supply. In the case of single- or monophase systems there is in addition the still more serious objection that the motor is not self-starting and must be rotated until the speed synchronizes with that of the generator. When the single-phase current flows in the armature of the motor, the resulting magnetic field rises and falls, but the position of the induced poles does not change, as already explained. If, however, the speed of the rotor is such that the position of the magnet poles relatively to the rotor becomes reversed at intervals corresponding with the reversal of the induced field, the rotation will be maintained; but if for any reason, such as a heavy and sudden increase of the load, the rotor is caused to lag and get out of step, it will immediately stop.

INDUCTION MOTORS.—Induction motors depend for their motion upon the interaction of the currents supplied to the field coils and the currents induced in the winding of the armature, but as before they are not self-starting unless use is made of the rotating field, obtainable with two- and polyphase currents. This may be effected in the case of single-phase motors by splitting the phase, which consists in dividing the single-phase currents over two windings, one of which contains sufficient extra inductance to sufficiently modify the phase. By the use of two-phase or polyphase currents in the suitably arranged field coils of a motor there is established a rotating magnetic field, which drags round the armature

as a result of the reactions of the magnetic fields. When using two-phase currents the coils are arranged in two sets, and when polyphase currents of two or more phases are used the number of windings is correspondingly increased. The armature of an induction motor consists of a laminated core, provided with a winding of very low resistance built up of heavy copper bars connected by copper end rings. Only induced currents flow in the armature, and there is therefore no necessity for slip rings and brushes or for a separate supply of continuous current, as in the case of the simple alternators, which require separate excitation. The force with which the rotor is dragged round depends upon the rate at which

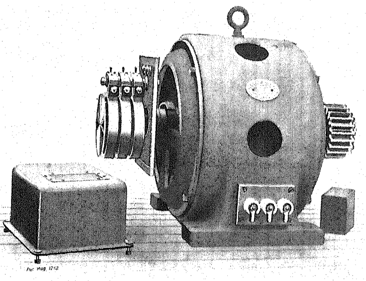


Fig. 529.—Three-phase Induction Motor

the armature bars cut the magnetic lines of force, and it is therefore clear that the speed of the rotor must always be less than that of the rotating field. When the load increases the motor will lag more, and as a result of the greater relative speed more lines will be cut per second, and the driving force will increase. In the same way as the load decreases the rotor speed will more closely equal that of the field, and the driving torque will be diminished. When starting the machine the rotor will be stationary and the torque will be a maximum, which is a feature of great advantage when the motor is required to start under its full load. Owing to the extra large starting current which flows when the rotor is stationary there is a possibility of the voltage of the supply mains being disturbed, and to prevent this it is customary to provide the armature with three windings and to supply three corresponding external resistances, which may be gradually cut out as the speed rises.

There are other arrangements for realizing the same effects, but they

need not be described here. An external view of a three-phase induction motor is shown in fig. 529. The field winding of the stator consists of three sets of coils, one for each phase, connected together at one end and to the three line wires at the others. The rotor winding is also divided into three groups, connected to one another at a common neutral point, and to the three insulated slip rings on the shaft. From the slip rings brush connection is made with the starting switch, which contains the resistances and the armature short-circuiting devices.

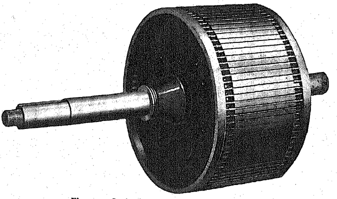


Fig. 530.—Squirrel-cage Rotor of Induction Motor

When no switch of this kind is provided the slip rings are dispensed with, and the rotor is of the simple squirrel-cage type, which consists of copper bars laid in the parallel slots of the core and joined at their ends by heavy rings, as shown in fig. 530.

TRANSFORMERS

Transforming of Continuous Current.—For the transmission of electrical power over any considerable distance it is essential, in order to prevent a serious loss in the operation, that the quantity of current should be small, and therefore that the voltage should be great; but it is not advisable to run industrial motors at voltages of over 500, and it is therefore necessary, before use, to transform the high-voltage current to a lower pressure. In the case of continuous current the simplest arrangement consists of a motor driven from the high-pressure mains, and coupled to a generator so wound as to produce current at the required voltage. Continuous-current transformers are generally used for transforming through small ranges, because very high-voltage continuous currents are rarely met with in practice, for the reasons already explained. They are frequently used as boosters at intervals along a distribution line for raising the pressure sufficiently to compensate for the fall, which generally amounts to only a few volts, or they may be used for balancing the distribution mains of a three-wire system, as will be described later.

Transforming of Alternating Current.—Alternating current at one pressure may be transformed into alternating current at another by means of an alternating-current motor, coupled as before to a suitably wound alternating-current generator, and it is also possible by means of coupled machines to transform from current of one kind, such as single-

phase, to current of another, as, for example, three-phase, or into continuous current. This last arrangement is the one most frequently re-

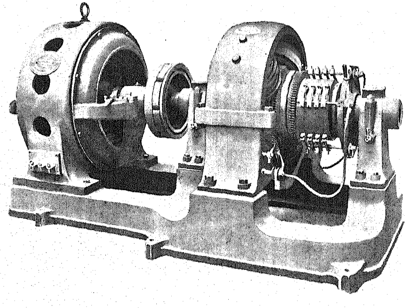


Fig. 531.—50-kw. Motor Generator for Converting 2000-volt, Three-phase Current to 240-volt, Continuous Current

quired, as continuous-current machinery is generally adopted for tramway, lighting, and many other power installations. A 50-k.w. motor generator

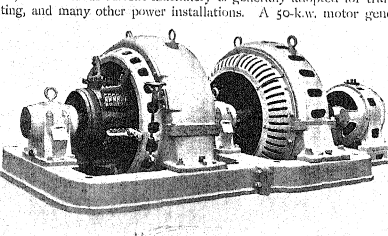


Fig. 532.—Alternating Current to Continuous Current Rotary Converter set

set for converting three-phase alternating current of 2000 volts into continuous current of 240-volt pressure for lighting purposes is shown in fig. 531. On the left will be seen the three-phase motor driven from the

high-voltage supply, and on the right the continuous-current generator coupled to the motor by means of a flexible leather-link coupling.

ROTARY CONVERTERS.—Rotary converters are also used for converting from alternating current to continuous current, or vice versa. There is, in certain machines, only one set of field coils excited by means of continuous currents in the usual way, and one armature winding, which is suitably connected to a commutator at the one side and to slip rings at the other. By means of the commutator the alternating current which passes into the machine is commuted and given out again as continuous current with only a small loss. When transforming from continuous to alternating current there is no difficulty in starting, but when converting single-phase, alternating current to continuous current means must be provided for running the machine up to its correct speed, as the synchronous motor portion is not self-starting. In the example illustrated (fig. 532) a small continuous-current motor is shown coupled directly to the machine, for the sole purpose of starting it.

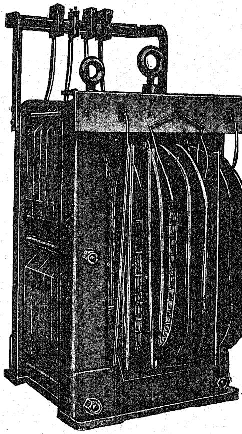


Fig. 533.—Westinghouse Static Transformer

STATIC CONVERTERS.—Alternating currents may be very readily transformed from one voltage to another by means of static converters, which do not involve the use of any moving mechanisms. A static transformer or converter consists of two separate windings, one of which is composed of a few turns of heavy wire, and the other of a large number of turns of fine wire, both wound together upon a common magnetic core. Upon the ratio of the coils depends the proportionate change of voltage which takes place in the transformation. When transforming from a high voltage to a low the high-voltage alternating current is passed through the large coil of many turns, and the fluctuation of the magnetic field created induces in the coarse winding a similar alternating current of lower voltage. It should be noted that static transformers can only convert alternating current into alternating current, because in the case of continuous current the magnetic field established

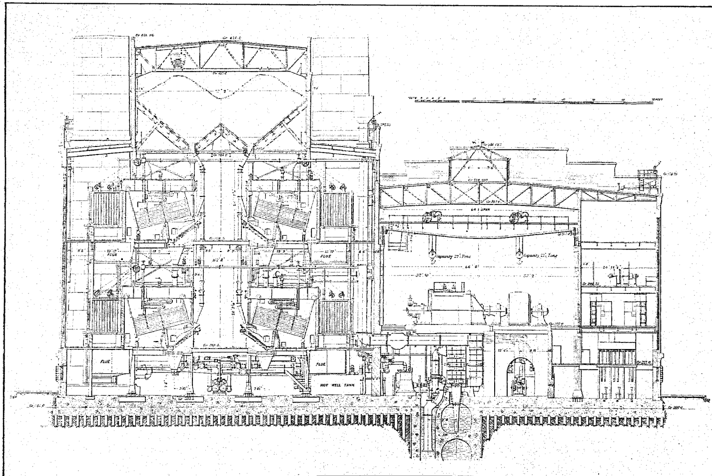
is continuous, and therefore the rate at which the magnetic lines of force cut the coils is zero.

Insulation is a matter of great importance in transformers which have to deal with very high voltages of from 2000 to 20,000 volts, and there are many constructions and many kinds of insulating materials used. In the example shown in fig. 533 the high-voltage coil is subdivided into a number of smaller ones connected in series and insulated from one another. In this way the actual difference in voltage across adjacent coils is reduced. The whole apparatus is immersed in oil, which insulates the windings from the outer casing and also helps to keep the temperature from rising to a serious extent.

Electrical Power: Production, Transmission, and Distribution.—Owing to the high capital cost of large copper cables it is necessary to reduce the quantity of current to be carried by raising the voltage, and this, again, in the case of high pressures, involves the use of alternating-current machinery. Under these conditions the high-voltage alternating current is transmitted through comparatively small cables to the distant substation, where it is transformed to suit the requirements of the consumers. If, for example, the alternating current is generated at, say, 6000 volts and transmitted to the substation, it might, in a typical installation, be reduced there in static transformers to alternating current of about 600 volts before its conversion in rotary converters into continuous currents of about 500 volts. From the substation the continuous current would be then distributed by means of feeders to the various motors, or lamps, or other electrical plant to be supplied.

A Typical Power Station.—A section through the Long Island City power-generating station of the Pennsylvania Railroad Company is shown in the Plate. Like the majority of such stations it consists of a boiler house, shown on the left, and an engine house, on the right; but in the example illustrated the latter is not so lofty as is usual in reciprocating-engine stations, owing to the use in this case of high-speed steam turbines, which occupy much less height and floor space. At the top of the boiler house are placed the coal bunkers, which are filled directly from the railway trucks by elevators and other mechanical means. On each of the lower floors are arranged two rows of Babcock and Wilcox water-tube boilers, each provided with steam superheaters, shown immediately under the water drums, and with economizers so placed in the flues behind the boilers as to abstract some of the heat from the escaping gases before they pass away to the chimneys. The ashes from the grates fall into hoppers and are then carried away by means of conveyers to the refuse trucks. Steam turbines are used in the engine house for driving the alternators, each of which is of 5500-kw. capacity, and underneath, in the foundations, is installed the condenser plant. The current is led from the machines to a switchboard, and thence through the transmission lines to the substations, where it is transformed down to the working voltage.

Wiring Diagram of a Station.—A diagram of the connections required for a section of a typical, three-phase, alternating-current generating station, and for the transformer substation, is given in fig. 534.



(95)

THE LONG ISLAND CITY POWER STATION FOR THE PENNSYLVANIA RAILROAD COMPANY'S SYSTEM

TRANSVERSE SECTION THROUGH THE BOILER HOUSE AND ENGINE ROOM SHOWING THE ARRANGEMENT AND THE LABOUR-SAVING APPLIANCES ADOPTED FOR THE HANDLING OF THE FUEL AND REFUSE

From *Engineering*, by kind permission.

Considering first the generating station, it will be seen that there are two alternators arranged to work in parallel and to feed the same set of cables. The exciters are continuous-current machines supplying current to the generator field magnets, the excitation of which may be controlled by means of the regulating resistances shown. From the three armature coils of the alternators separate connections are led through ammeters, which register the flow of current, and through safety fuses and switches to the line bus-bars on the main switchboard. If one alternator alone is running, and it is desired to run the second, it is essential that the latter should be run up not only to the correct speed before it is connected to the common bus-bars, but also that the connections should not be made until both machines run in step, so far as the phase is concerned, in order to prevent a serious disturbance of the pressure. The synchronizer shown is provided to enable the operator to determine the moment when the machines run in step, and when he may close the main switches connecting the second machine to the

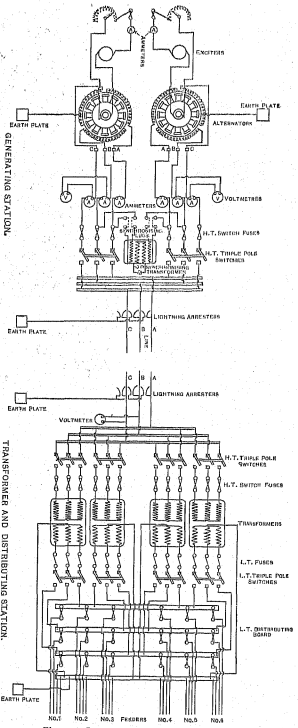


Fig. 534.—Power Station Electrical Wiring Diagram

bus-bars. From the switchboard three transmission lines, A, B, C, carry the current to the substations, of which there may be several. In this particular example the current is only converted to alternating current at a lower voltage, and static converters alone are therefore employed.

THE THREE-WIRE SYSTEM.—A continuous-current distribution circuit of the simplest kind consists of two wires, one for carrying the current to the plant where it is consumed and the other for returning it at a lower voltage to the generator. By the adoption of a three-wire system, illustrated diagrammatically in fig. 535, a considerable saving in the quantity of copper required for the conductors carrying the same total load as before may be effected by combining two simple circuits and substituting for the two return wires a single one, the diameter of which is usually made about one-half that of either of the outers. Two generators, each of, say, 220 volts, are connected as shown across the lines, and as a result of the series connection of the generators there is across the outers a pressure of 440 volts, while the pressure between each of the outers and

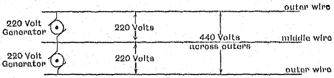


Fig. 535.—Three-wire System

the middle wire is only 220 volts. This arrangement is particularly convenient in combined power and lighting installations where the motors run at, say, 440 volts and the lamps at 220 volts. It will be seen that the middle wire has only to carry the difference of the current flowing in the two low-pressure circuits, and that when the loads are equally balanced the middle wire will carry no current. If desired, a pressure across the outers of 1000 volts could be obtained with the use of two 500-volt machines, and this arrangement is sometimes adopted when the length of the distribution lines is considerable.

STORAGE BATTERIES.—Primary batteries are only suitable for the production of comparatively small quantities of electricity as a result of the consumption of some such metal as zinc, and the constancy of the pressure cannot be maintained for long when the battery is worked at any considerable rate, owing to the polarizing effect of the gases evolved, which gather upon the surfaces of the elements. By means of secondary batteries the mechanically generated currents may be stored up for future use without involving the permanent consumption of the elements employed, or without any serious loss of power.

Many eminent scientific names are associated with the problem of storing electrical energy by direct chemical means, and the fundamental ideas involved are old. Probably the name most closely associated with the question is that of GASTON PLANTE, who, in 1860, described the lead lead-peroxide type of cell now commonly used with but few modifications. In this cell a negative plate of lead in a spongy form and a

positive plate covered with a layer of lead peroxide are required, and to produce these it is necessary to first subject the metallic lead plates to a forming process which requires considerable care and time. Modern cells are generally made with pasted plates—that is, both the positive and the negative plates consist of lead grids, the spaces of which contain the lead and lead dioxide in the form of pastes, and in this way the forming process is avoided. There has been considerable discussion as to the precise chemical changes that take place in an accumulator during the operations of charging and discharging, and it appears that the reactions vary to some extent with the conditions of working. An accumulator

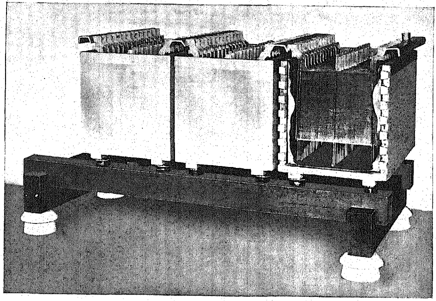


Fig. 536.—Set of Three Tudor Accumulator 25-plate Cells

in the charged condition consists of a negative plate coated with porous metallic lead, and a positive plate pasted with lead dioxide, $Pb\,O_2$, both immersed in water acidulated with sulphuric acid. When in good condition, and fully charged, the positive plate appears dark, with a characteristic purple bloom. In the discharged condition the lead of the negative plate becomes sulphated, and gaseous hydrogen is evolved, while the dioxide of the positive plate also becomes converted into lead sulphate, which has a grey appearance. Expressed in chemical formulæ the reactions may be explained as follows: During the charging of the cell after a previous discharge the water is split up by the current into hydrogen and oxygen, and the reactions at the positive plate are—

$$Pb\,SO_4 + O + H_2O = Pb\,O_2 + H_2SO_4,$$

and the reactions at the negative plate are—

$$Pb\,SO_4 + H_2 = Pb + H_2SO_4.$$

During the discharge the reactions are: At the positive plate:

$$PbO_2 + H_2 + H_2SO_4 = PbSO_4 + 2H_2O,$$

and at the negative plate:

$$Pb + H_2SO_4 = PbSO_4 + H_2.$$

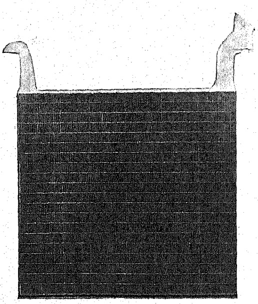


Fig. 537.—Tudor Positive Plate

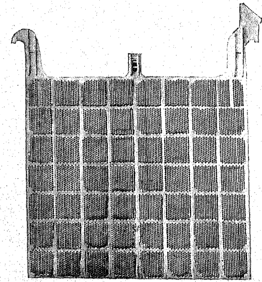


Fig. 538.—Tudor Negative Plate

During the operation of charging, electrical energy is expended in effecting the chemical changes, and this electrical energy is again given off as a result of the chemical reactions that take place during the discharging process.

As the action is a chemical one, there is a definite voltage for each pair of plates, but by placing a sufficient number of plates in series any desired voltage may be obtained. Thus, between each pair of plates of the series, when fully charged, there is a voltage of about 2.6 volts; but as the voltage falls during the discharge it is safer, in calculating the number of cells required, to reckon the voltage per cell as 1.8 volt. For a total voltage of 100 the number of cells required would thus be 55.

As regards the rates at which the battery may be charged and discharged there are limits, determined by the danger of the plates becoming buckled through unequal expansion. By increasing, however, the area of the surfaces, as, for example, by grouping in each cell a number of plates in parallel, the capacity of the battery may be made as large as desired. Three Tudor type accumulator cells, each of which has twenty-five plates,

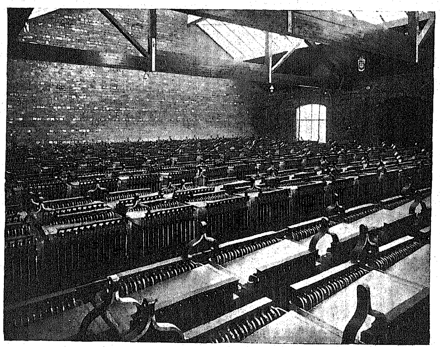


Fig. 539.—500-volt Battery of 270 A.B.P. Type Accumulator Cells

are shown in fig. 536 mounted in lead-lined wood boxes and supported upon insulators which prevent loss of current by leakage. The positive plates of each cell are metallically connected to one another and to the similarly joined negative plates of the adjoining cell, and the conductors are respectively led to the extreme negative and positive bars of the battery. In figs. 537 and 538 are shown the positive and the negative plates, in the interstices of which the paste is securely held. There are other types of accumulators, which practically differ only in the method of constructing and forming the plates. The illustration, fig. 539, shows a 500-volt battery of 270 A.B.P. type accumulators which may be discharged during ten hours at the rate of 49 amp.

CHAPTER VIII

MATERIALS OF CONSTRUCTION: TIMBER—STONE —CEMENT—IRON AND STEEL, ETC.

TIMBER

Many of the greatest advances in engineering are marked by the introduction of some improved material of construction of greater strength and tenacity. For many purposes timber has been largely displaced by

wrought iron, and wrought iron by mild steel, which in turn is being replaced by chrome, nickel, and other special steels of improved qualities. Although timber is no longer used for the construction of large bridges, buildings, or ships, where great strength in comparison with weight is required, the use of wood for many purposes is universal, owing very largely to the great ease with which it can be worked.

SOFT WOODS AND HARD WOODS.—In general the different qualities of timber used for engineering purposes may be divided into two classes, namely Soft Woods and Hard Woods. Under the soft-wood heading may be included the Baltic timbers, the red pines of the Danzig, Riga, and Memel districts, and spruce, together with the yellow pines of America. To the hard-wood class belong such woods as oak, ash, elm, beach, teak, mahogany, and greenheart.

In estimating the strength of timber, oak is generally taken as the standard of comparison for both hard and soft woods, its stiffness and strength being reckoned as unity. Any comparison is, however, indefinite, as the actual strength of a timber is more determined by the absence of such flaws as dead wood, knots, and sap wood.

Of the Baltic timbers, Danzig red is the strongest and stiffest, and in these respects it surpasses oak, but owing to the frequent presence of defects the actual strength from the structural point of view is not so great. American red pine is extensively used for internal joinerwork, for which it is very suitable. It does not warp readily, and it is easily worked without being too soft.

Elm is employed in damp situations, and is therefore suitable for the construction of foundations; larch is also largely used under similar conditions, and more particularly for railway sleepers, where durability under exposed conditions is of first importance. Greenheart is also used for piles and foundation work not only on account of its durability but because of its strength under compression, which is 1.6 times that of oak. It is a very hard wood and is difficult to work.

SEASONING AND PRESERVATION.—Wood in its natural green state contains a large percentage of moisture, not only in the pores but also in the substance of the cells, and the presence of this moisture seriously affects the strength and permanence of form. To remove the water, timber is subjected to a prolonged natural seasoning process, after it is cut down, by storing it under cover and at the same time allowing dry air to circulate freely around it. As the water contained in the pores evaporates away the weight of the timber diminishes, but the strength is not increased to any considerable extent. As the seasoning process is continued the water in the substance of the wood is also dried out and the strength then rapidly improves. The point at which the moisture in the fibres commences to dry out is known as the fibre-saturation point, and it is only after this point is reached that the strength appreciably increases. When artificial means are employed for seasoning the timber practically all the moisture can be removed, and in the case of spruce the strength can be increased to four times that of the wood in the green state. When the timber is once more

exposed to the weather it reabsorbs some moisture, and the strength decreases unless the wood is subjected to some preserving process such as creosoting, in which the pores of the timber are completely filled with oily residues. Moisture is in this way effectually excluded, and the durability of the timber is greatly increased in exposed situations, as, for example, in the case of railway sleepers. Other preservatives are used in a similar way, and in some processes not only is the strength and durability of the timber improved at a reasonable cost, but the inflammability of the wood is at the same time reduced, while in other processes the use of a preserving liquid is entirely avoided.

STONE

CHOICE OF STONE.—Stone as a building material is indispensable for the great majority of permanent engineering works, and when properly chosen to suit the climatic conditions it is the most durable and least expensive, so far as upkeep is concerned, of all the materials of construction. Choice is, however, frequently limited to the stones quarried locally, as in many cases the cost of transport is serious.

In choosing a stone for building purposes a careful examination should be made of the condition of surrounding buildings, as there still is no test of durability more certain than that of actual use. Even with all care the choice of a suitable quality of stone to suit a particular locality may not be fortunate, as in the case of the carefully selected Permian limestone used in the building of the new Houses of Parliament. The Permian limestone employed was a Dolomitic or Magnesian limestone, which later experience has shown to be unsuited to the present smoky atmosphere and the weather conditions of London.

CLASSIFICATION OF STONE.—From the point of view of the engineer stone may be best classified according to its geological formation rather than upon a chemical basis, as the composition of many of the rocks is very complicated, and in many cases gives little indication of their practical value. Rocks may therefore be broadly classified as: 1. IGNEOUS, comprising the rocks erupted in a fluid condition from the earth. 2. AQUEOUS or SEDIMENTARY, comprising all those that have been deposited mechanically or from solution, or which have resulted from the decay of other materials. 3. METAMORPHIC rocks, which, as the name implies, have been produced as the result of the alteration of the other formations under the action of heat or water.

IGNEOUS ROCKS.—Of the igneous rocks GRANITE is the most important and the most valuable for constructional purposes owing to its great hardness and the closeness of its crystalline structure. It is a crystalline granular mixture of silica, felspar, and mica, in which the silica, or, as it is better known, quartz, generally acts as the cementing material, binding the felspar and mica together. The proportion of silica varies from about 65 to 80 per cent, and in general the granites are very hard and tough and correspondingly difficult to work. They are particularly valuable for the building of piers or marine works where very large and sound blocks

are required. In all cases careful selection is necessary, as in some qualities of granite the felspar and also the mica are subject to rapid decay when exposed to the weather. BASALT, WHINSTONE, and GREENSTONES are not suitable for building purposes, not only on account of their extreme hardness, but also from the æsthetic point of view, as the appearance of these rocks is very dull. They are principally used for road making and paving.

SEDIMENTARY ROCKS.—SANDSTONE is one of the most important of the sedimentary and at the same time one of the most variable of the stones. It largely consists of fine grains of quartz bound together by some cementing material, which may be iron, clay, lime, or silica. Ferruginous sandstones are readily recognizable by their characteristic red and yellow colours, and so far as appearance is concerned they are very suitable for building purposes. The Devonian or Old Red Sandstones, the Carboniferous and the Triassic or New Red Sandstones, are most frequently employed, but sandstones of a particularly hard though somewhat unfavourable colour are quarried from the Silurian formations.

The LIMESTONES are sedimentary rocks formed in water by the accumulation of calcareous remains or by the precipitation of lime. They are mostly quarried from the Devonian, Carboniferous, Permian, and Oolitic formations. When crystalline they may be highly polished, and some of the limestone marbles are valued for decorative purposes. PERMIAN LIMESTONE or DOLOMITE contains magnesia, and has a close amorphous granular structure very different from some of the marbles. It is obtainable in large blocks, and being easily worked it is extensively used for constructional purposes. As already mentioned it has been used in the Houses of Parliament, with, however, in this case, not wholly satisfactory results.

PRESERVATION OF STONES.—All stone is more or less porous, and absorbs water, which tends to make it deteriorate in exposed situations, and especially in city areas where the proportion of acid in the moisture of the atmosphere is considerable. Granite absorbs water in the proportion of 0.75 per cent of its bulk, while sandstone absorbs about 10 per cent, limestone 1.0 per cent, Oolitic freestones 17 per cent, and slate 1.0 per cent. To some extent the decay of stone can be retarded by treating the surface with some siliceous compounds, or in certain cases with wax, which forms a protective coating within the pores of the stone; but their beneficial effect is not always certain.

CEMENT

Stone is an expensive material, especially when the cost of transport is considerable, and it is costly to work. Its weight also is considerable, and for many purposes where lightness and ease of handling are of importance other materials, such as brick and cement, must be adopted. Within recent years the use of cement reinforced with steel has rapidly extended for structures of every description, and especially for the construction of fireproof buildings.

MAKING OF CEMENT.—Cement is now manufactured from many kinds of raw materials, but in the earlier days of the industry the principal ingredients were most frequently clay and chalk. Precise methods and highly developed machines are now adopted in place of the rough and somewhat primitive arrangements which were for many years considered sufficient, and as a result the composition of the product is kept within the very narrow limits required for consistent results. In the modern process the ingredients, which may be, for example, limestone and shale of various kinds, are carefully ground together in dry mills to the consistency of meal, and fed into rotary kilns which work continuously. Coal fuel in a finely powdered condition is blown in by means of a blast of air, and the clinker produced by the fusion of the limestone and shale is drawn off and ground. As the fuel is burnt almost out of contact with the charge there is little danger of impurities such as the sulphur being carried over into the cement. Any loosely combined lime is slaked and rendered harmless by the addition, during grinding, of water, which also determines the time of setting of the cement.

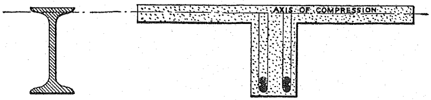


Fig. 540.—Reinforced Concrete Equivalent of a Steel H-section Girder

PORTLAND CEMENT is largely made from dry raw materials of the limestone and shale classes, but large quantities are also made by wet processes from chalk and clay. Blast-furnace slag mixed with limestone is also used by some makers. ROMAN CEMENT is typical of the "natural" hydraulic cements made from natural raw materials which are burnt together in correct proportions without previous intimate mixture.

COMPOSITION OF CEMENT.—There is at present no definite explanation of the chemical changes that take place in the hardening of cements, and the composition itself, so far as the essentials are concerned, is also indefinite. In the case of Portland cement the principal constituent is supposed to be a solid solution of tricalcium aluminate in tricalcium silicate, known as alite. When water is added to this substance dissolution takes place, and less soluble hydrates are formed in hard coherent crystalline masses. The explanation of the setting of cement is based upon what is now known regarding the hardening of plaster of Paris, in which dissolution is effected by the agency of a quantity of water small in comparison with the material dissolved and deposited.

FERRO-CONCRETE.—Within recent years the use of cement has extended for structures in which not only compression but also tension stresses require to be borne. In these cases the cement is reinforced with steel rods, so disposed in the body of the material as to take the

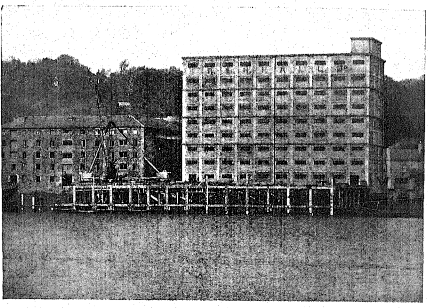


Fig. 541.—Hennebique Ferro-concrete Structure

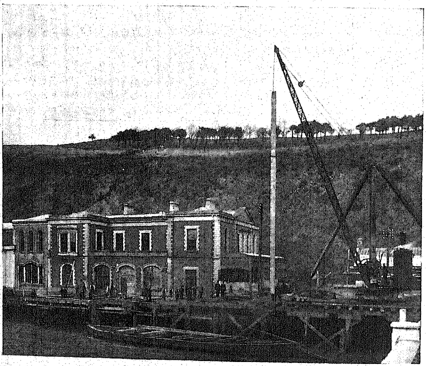


Fig. 542.—Ferro-concrete Pile, 62 ft. long, section 16 in. by 16 in.

tension stresses, while the compression is borne by the cement. There are now many systems which differ generally in the arrangement of the reinforcing bars, and a description of one typical method will sufficiently illustrate the principal features of such structures. In the Hennebique ferro-concrete construction the equivalent of a steel H-section girder would be composed of a top member of concrete of sufficient area to withstand the compression stress, and of a lower member reinforced, as shown in fig. 540, with steel tension rods which take the tension stresses. A special treatment of the web is also necessary, as the concrete is not itself able to

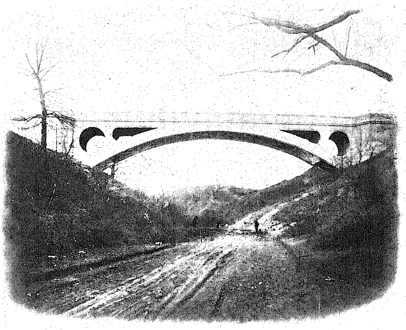


Fig. 543.—Ferro-concrete Bridge, Kahn System. Length of span, 118 ft.

withstand the shearing forces to which it is there subjected. Stirrups of hoop steel are bent around the tension bars, and carried upwards through the web. In the construction of concrete beams both straight and bent bars are used, and the arrangement is such that the bars and stirrups combined form triangular frameworks, which resist the tendency to deformation of the concrete under load. It is found that the concrete grips the metal surfaces, which do not require to be specially notched or roughened, and owing also to the practical equality of the coefficients of expansion for steel and concrete there is little danger of the structure being severely strained even in the case of fire. This latter feature is of great importance in the construction of fireproof buildings. Experience has shown that the steel embedded in the concrete out of all contact with the atmosphere is free from oxidation, and that it is not subject to deterioration as in the case of ordinary structures.

The use of ferro-concrete is rapidly extending, and its industrial applications are very varied. In fig. 541 is shown a typical ferro-concrete structure built on the Hennebique system, and in this case ferro-concrete is used throughout, not only in the building, but also for the river jetty. Another example of a ferro-concrete foundation pile being placed in position preparatory to driving is shown in fig. 542. This great pile—62 ft. long, 16 in. by 16 in. section, and 8 tons weight—was used in the construction of the Waterford North Viaduct for the Great Southern and Western Railway (Ireland). Objections are sometimes raised to the use of concrete for certain public structures on æsthetic grounds; but although the appearance cannot equal that of a stone erection, many graceful bridges have already been built, and the compensating advantages are numerous. In fig. 543 is illustrated a bridge of 118 ft. clear span, built entirely of ferro-concrete on the Kahn reinforcing system.

IRON AND STEEL, ETC.

CHEMICAL COMPOSITION.—Iron and steel are, from the constructional point of view, the most important of all the metals, and their properties and manufacture will accordingly be first considered. Iron in the practically pure condition is too soft and malleable for most purposes, and its value lies in its high magnetic permeability, which makes it very suitable for the magnetic-field portions of electrical instruments and machines.

MALLEABLE OR WROUGHT IRON approaches closely in its properties to pure iron, but the use of wrought iron is being in many cases abandoned in favour of MILD STEEL. Commercial iron and steel are metallic mixtures or alloys of pure iron and of carbon, which exercises a wonderful effect on the physical properties of the product. Other metals are also used with remarkable results, especially considering the small proportion of the added metal; but the element which chiefly characterizes the steels of the present time is carbon in one or other of its many forms. Microscopic investigation has within comparatively recent times placed the whole question of the structure of the many varieties of steel and steel alloys upon a scientific basis, and the conditions determining such phenomena as hardening and tempering can now be determined with great precision. This subject will be referred to later, when dealing with the effects of slow and rapid variations of temperature upon alloys of steel. Carbon combines very readily with iron, and it occurs in the iron either as free graphite or as combined carbon, Fe_3C, which so far is the only carbide of iron definitely known to exist.

PIG IRON.—In the manufacture of pig iron, from which steel and the steel alloys are ultimately derived, the iron ores, previously converted by calcination to the oxide form, are smelted in the blast furnace (fig. 544) with carbonaceous fuel and a flux of limestone. At the high temperature, which is maintained by an air blast, the ferric oxide is reduced by the carbon of the fuel, with, as a result, the formation of metallic iron and CO_2; but, owing to the rapidity with which iron and carbon combine, the iron

produced by the furnace contains as much as 4 per cent of carbon, together with silicon and such impurities as sulphur and phosphorus obtained from the fuel and the ore. The presence of the silicon and of the carbon makes the pig iron very fluid at the smelting temperature, and it thus separates

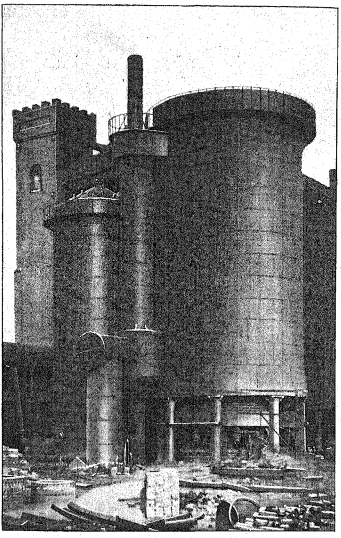


Fig. 544.—Blast Furnace for the Production of Pig Iron

readily from the gangue or slag. To prevent, however, the formation of rich ferrous silicates, which are only reducible with difficulty, a flux of limestone is added to the charge, and more fusible silicates of lime and alumina are in consequence produced instead. For commercial purposes the iron is tapped from the furnace and cast in open sand moulds into the well-known form of bars or pigs. It is, however, becoming more common

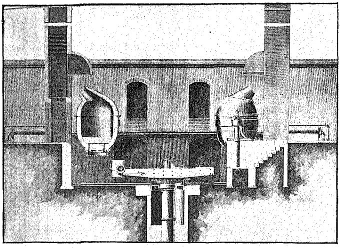
to cast large pieces of machinery directly at the blast furnace, a system that saves the expense of remelting the pigs in cupolas.

There are two chief kinds of pig iron, the structures of which depend upon the percentage of carbon present and upon the condition in which it exists; but the presence of other substances modifies the physical properties to a very considerable extent. In GREY CAST IRON the bulk of the carbon exists in a free uncombined graphitic condition, and the flakes of black graphite can be readily detected at fractured surfaces. WHITE PIG IRON, on the other hand, has the bulk of its carbon in a combined condition, as carbide, Fe_3C. Between these extremes there is a variety of grades, as, for example, MOTTLED IRON, which consists of white iron with particles of grey iron throughout its bulk. White iron is harder and more brittle than grey iron, and, unlike grey iron, it becomes pasty when melted and is therefore unsuitable for foundry purposes where fluidity is essential. Grey iron may be converted into white iron by sudden cooling, which makes a portion of the free graphitic carbon combine with the iron. A hard white iron skin may be thus obtained in castings of soft grey iron by pouring the molten metal into chilled moulds, as in the manufacture of chilled rolls. Various grades of iron, differing greatly in character, may be obtained by varying the proportions in which other constituents are present. Carbon in the free state tends to weaken the iron by forming layers between the crystals, and the strength is particularly affected when the flakes are large.

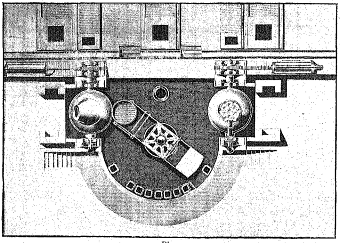
ELEMENTS IN PIG IRON.—SILICON plays a very important part in the constitution of cast iron. It directly tends, as in the case of carbon, to harden the metal, but indirectly it softens it to a much greater degree by preventing the combination of the carbon, which then appears in the soft graphitic state. PHOSPHORUS very readily enters the iron from the fuel, and for many foundry purposes its presence in quantities of about 1 per cent is not objectionable, as it improves the fluidity of the metal. In larger quantities, however, it seriously affects the tensile strength. Pig iron for the production of steel should be as free from phosphorus as possible, and in such cases materials free from phosphorus are chosen for the charge. SULPHUR in very small quantities has a beneficial effect upon cast iron for foundry purposes, but for the manufacture of steel the presence of 0.03 per cent of sulphur makes the metal unsuitable. MANGANESE, which is always present, tends in large quantities to make the iron brittle. Special manganese-iron alloys are, however, used in the manufacture of steel, as the manganese allows the iron to take up a larger proportion of carbon. SPIEGELEISEN, containing from 6 to 30 per cent of manganese, and FERRO-MANGANESE, containing 80 per cent of manganese, are regularly manufactured for the purpose. Silicon alloys of both iron and ferro-manganese are also specially manufactured.

WROUGHT IRON.—Wrought iron, which is soft and malleable, contains about 99.5 per cent of iron, with about 0.2 per cent of carbon. It is difficult to draw a definite line of demarcation between wrought iron and mild qualities of steel, but the latter may be considered as having more than $\frac{1}{4}$ per cent of carbon. In the manufacture of wrought iron from pig iron

the pigs are remelted in a puddling furnace, which is generally fired by means of gas and maintained at a temperature sufficient to melt the pig iron but not the decarbonized metal, the melting-point of which increases as it becomes more like pure iron. As the iron under the decarbonizing



Elevation



Plan

Fig. 545.—Arrangement of Bessemer Steel Plant

action of the oxygen of the flux becomes purer it also becomes more plastic, and in this condition it is gathered into spongy, semiplastic masses which contain a certain proportion of liquid slag. Each mass is therefore composed of a large number of globules of iron surrounded by a thin layer of slag, which is largely expelled during the subsequent hammering and squeezing to which it is subjected. While still hot the hammered balls

are rolled out into rough bars, and after reheating are subjected to further rolling, which welds the globules of iron together, and at the same time, by elongating them, produces the characteristic fibrous structure of wrought iron.

Commercial malleable iron produced in this way contains about 99.5 per cent of pure iron, with about 0.2 per cent of carbon and 0.1 per cent of silicon with traces of other impurities. It becomes plastic at a red heat, and can then be readily welded; but its melting-point is as high as 2800° F., the melting-point of pig iron being 2100° F. and that of steel about 2500° F.

STEEL.—Steel contains smaller proportions of carbon than does cast iron and a larger percentage than wrought iron, and it may be produced either by eliminating some of the carbon of the former or by adding carbon in sufficient quantity to the latter. Cast iron can be reduced to steel by two processes, either by means of the Bessemer converter or in the open hearth furnace, while wrought iron can be carbonized to form steel by the cementation and crucible processes.

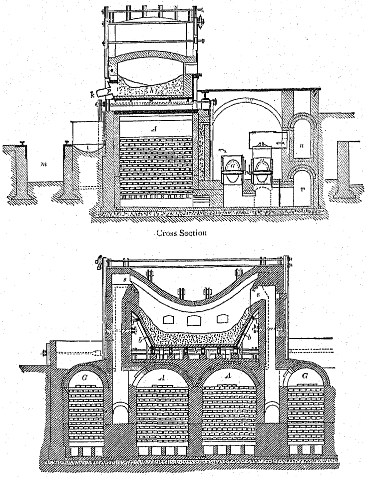
BESSEMER STEEL.—In the Bessemer process the molten cast iron is poured into the converter, which, as shown in the section (fig. 545), is a large pear-shaped vessel lined with some refractory material and supported upon hollow trunnions through which an air blast passes towards the bottom of the vessel and thence up through the molten metal. In this way the carbon is completely burned out of the iron. When all the carbon is burned out, the metal in the converter resembles wrought iron, with the exception that it does not contain slag throughout its mass, and is therefore more homogeneous. It should be noted that the converter is rotated about its trunnions into a horizontal position before the air blast is turned off or on, and that in the vertical position the pressure of the blast is sufficient to prevent the metal from flowing down into the blast tuyeres. After the blowing process, when the carbon is burned out of the metal, the converter is turned into the horizontal position and the blast turned off. Spiegeleisen and ferro-manganese, which, as already stated, are special alloys rich in carbon and manganese, are added in sufficient quantities to give the converter charge the correct proportions of carbon and manganese required for the particular brand of steel being manufactured.

THOMAS-GILCHRIST PROCESS.—Iron as free as possible from sulphur or phosphorus is best suited for use in the acid Bessemer converter, which is lined with refractory clay. Phosphoric irons may, however, be successfully converted by means of the Thomas and Gilchrist basic process, in which the converter is provided with a basic lining of dolomitic limestone and a suitable cementing substance.

SIEMENS-MARTIN OR OPEN-HEARTH PROCESS.—It is difficult under any conditions to eliminate all the phosphorus, and recently the use of the Bessemer process has been largely discontinued in favour of the Siemens-Martin open-hearth process, from which very uniform results are obtainable.

The furnaces used in this process are similar to those adopted in the manufacture of wrought iron, but they are frequently of very large capacity.

Gas and air are passed through regenerators (fig. 546) underneath the furnace, in which they are heated to a high temperature before being brought together in the furnace, where combustion takes place, and two sets of regenerator chambers are employed, the one set being heated by the burned gases as they escape, while the other gives up its heat to the incoming air and gas. By heating the gases in this way a temperature is



Cross Section

Sectional Elevation

Fig. 546.—Open-hearth Steel Furnace with Regenerators

maintained sufficiently high to keep the decarbonized iron in a fluid condition preparatory to the introduction of the Spiegeleisen or ferro-manganese; and there is the further advantage of economy of fuel. As in the Bessemer converter, both acid and basic linings are employed, the latter being used when the charge contains phosphorus. When the proportion of phosphorus is considerable, burnt lime is also added to the charge, as the slag produced absorbs the phosphorus and other impurities.

CRUCIBLE OR CAST STEEL.—In the cementation process for the production of crucible or, as it is sometimes called, cast steel the wrought iron in the form of small bars is packed into hermetically closed crucibles which contain powdered charcoal. The crucibles are then placed in furnaces and maintained at a cherry-red heat for several days, during which period the iron absorbs as much as $1\frac{1}{2}$ per cent of the carbon. At the conclusion of the cementation process the carbonized bars, known as blister steel, are remelted and cast into the desired shapes. In the more recent processes the wrought iron is actually melted down in the air-tight crucibles, as the cementation action is then more rapid. A somewhat similar process is adopted for case-hardening the working surfaces of mild steel or wrought-iron pieces, and the reverse process is commonly adopted in the manufacture of malleable castings. The brittle castings, in the latter instance, are packed into crucibles and covered with oxide of iron, which, at the temperature of the furnace, abstracts some of the carbon and leaves the castings in a malleable condition.

MICROSCOPIC STUDY OF IRON AND STEEL.—Microscopic examination of the polished surfaces of metals, etched and stained according to circumstances, has led within recent years to an extensive knowledge of the constitution of metals and alloys when produced under various circumstances. When a mixture or alloy of different metals cools from a fluid state the substances of higher melting-point solidify first, and are surrounded by the substances which solidify later; but physical changes continue to take place even after solidification, and it is in the determination of these changes that the microscope has proved itself so valuable. By chemical analysis the constituent elements can be determined both quantitatively and qualitatively, and by means of the microscope the conditions under which they exist can be observed. When steel containing about 0.89 per cent of carbon is allowed to cool slowly, the structure becomes banded after solidification, and under the microscope it appears to be composed of fine layers of FERRITE, or pure iron, and carbide of iron, Fe_3C, known as CEMENTITE. Ferrite and cementite occurring in this way are called PEARLITE, from the characteristic appearance, which was first noticed by Dr. Sorby. When the percentage of carbon exceeds 0.89 the proportion of ferrite decreases and free cementite, apart from the cementite in the pearlite, takes its place. In the cementation process of making tool steel described above these conditions prevail, and the hardness of the steel produced is largely due to the presence of the free carbide of iron, which is an extremely hard substance. To a large extent the structure is determined by the rate of cooling, and when the mass is suddenly quenched, such substances as HARDENITE and MARTENSITE, which are probably solid solutions of carbon, and the carbide of iron in ferrite, make their appearance. When steel, therefore, is allowed to cool naturally in air, it is composed largely of pearlite, with ferrite and free cementite in proportions depending upon the proportion of carbon in the steel. When, however, the steel is quenched from the hot condition, as in the hardening process, Martensite with or without a proportion of cementite, takes the place of the pearlite

and ferrite. According to the allotropic theory, the changes that take place are explained by assuming that iron is capable of existing in three allotropic forms, known as alpha, beta, and gamma iron, the alpha iron being stable below 690° C. and the gamma above 800° C. This theory explains all the phenomena of hardening, tempering, and annealing, and it is very generally used when describing the changes that take place. When pure iron is allowed to cool there are three points at which the rate of the fall of the temperature diminishes while the iron changes from the one condition to the other, and the positions of these points on the temperature curve may be modified by the addition of some other substance, such as nickel, chromium, vanadium, and aluminium, which tend to prevent segregation and exercise a considerable influence on the homogeneity and closeness of grain of the steel. A series of micrographs of steel, reproduced from Professor Robert-Austen's book, *An Introduction to the Study of Metallurgy*, is shown in the Plate. The central specimen shows the structure of the original forged blister steel. After being heated to 1000° C., and then worked and slowly cooled, the mass is largely composed of pearlite, as indicated by Sample 1. No. 2 shows the condition after heating to 850° C. and quickly cooling in air; and No. 3 shows the effect of cooling in water instead of air, with the consequent production of Martensite. No. 4 shows the effect of cooling in brine after heating to a high temperature, and No. 5 is the result of still further cooling in iced brine. In No. 6 the metal has been quenched from a temperature near the melting-point, and in this example the metal is burnt and useless for practical purposes. No. 7 shows the effects of annealing and the production of cementite with pearlite, while No. 8 shows the return to practically the original condition by heating to 850° C. any of the specimens except the burned one, No. 6, and allowing it to cool after working it.

Two micrographs of bronze, one treated by the Willans and Robinson "Eatonia" process of casting and the other cast in sand in the ordinary way, are also illustrated in the Plate, to show the effect of cooling metals at certain temperatures. By the Willans process of casting, the metals of the alloy are prevented from segregating, and the structure is much more homogeneous and compact, and therefore more suitable for the construction of bearings, pump rods, and similar purposes.

ALUMINIUM.—Aluminium has become an essential material for many industrial purposes, and the production has grown enormously with the increased demand. It is largely used as an alloying material in the manufacture of steel and aluminium bronzes, and for some time its use was extensive in the manufacture of motor-car gear-box and cylinder casings, where lightness is of importance. When alloyed with a small proportion of magnesium its properties are in all respects improved, and Magnalium, as the alloy is called, is preferred to commercial aluminium. Duralumin is an aluminium alloy possessing great strength and ductility. Its constitution has not been published, but the tensile strength of the alloy depends upon the mechanical treatment to which it is subjected in the process of manufacture. It is supplied in the form of rolled plates and rods, and when cast the metal loses its excellent properties.

CHAPTER IX

LOCOMOTIVES

TRANSPORT.—A very large proportion of the total power produced throughout the world is utilized in the transport of passengers and materials from one place to another both by land and sea. In the case of marine propulsion the power required is particularly great, especially for high speeds, as the resistance due to the friction of the water upon the skin of the ship increases rapidly with the speed. Thus, for example, the *Lusitania*, which has a displacement of about 38,000 tons, requires a power of about 68,000 h.p. to maintain a speed of 25 knots, whereas the old *Great Eastern*, which displaced over 32,000 tons, required only 12,000 h.p. to maintain a speed of 13 to 14 knots. On land the conditions are very different, and such large units are seldom required even in the largest city power stations, which have rarely a total capacity of more than 40,000 h.p.

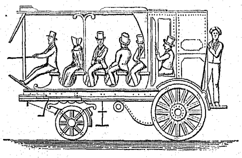


Fig. 547.—The Handcock Steam Carriage

Upon land the bulk of the heavy freight and fast passenger traffic is now confined to the railways, but for small distances, especially in city areas, the use of tramways on the public thoroughfares has enormously increased within recent years. Motor vehicles and steam tractors, which do not require any form of permanent way, and are therefore not limited to definite routes, have also come into very general use, but their adoption upon any universal scale will largely be determined by the future improvement of the roadways.

STEAM CARRIAGES.—Before the introduction of the locomotive, which has so greatly influenced the progress of civilization, the passenger and general traffic was in the hands of powerful coach owners, who ran horse-driven coaches in stages between the widely separated towns of the country, and it was the opposition of these owners and of the trustees of public roads that blocked the introduction of steam carriages, which, it was thought, would completely supersede the highly developed coaching systems. Although it is certain that, with encouragement, the steam carriage would have been brought to a condition of some perfection, its failure was partly due to mechanical defects and to the unsuitability of the roads. For several weeks in the year 1831 the HANDCOCK STEAM CARRIAGE (fig. 547) was run between Paddington and the Bank of England; but the frequent necessity for repairs ended in the abandonment of the scheme. It is known that JAMES WATT devoted some attention to the substitution of steam for horse power on the public roads, but he does not appear to have made any definite proposals, and it is to

THE STRUCTURE OF METALS

Fig. 1. Sections 1 to 8 illustrate some alterations of structure produced in the central specimen of Forged Blister Steel by variation of the thermal treatment.

Fig. 2. Micro-Section of Cast Phosphor Bronze alloy having an ultimate tensile strength of 13 tons per sq. inch.

Fig. 3. Micro-Section of the same Phosphor Bronze alloy treated by the "Eatonia" process. The structure is finer, and the ultimate strength is increased to 21 tons per sq. inch, but the percentage elongation remains unaltered.

MURDOCH, an engineer in the employment of Boulton & Watt, of Birmingham, that the credit of first applying steam in this way is due, although the carriage which he constructed in 1784 was only a model. Among the early engineers whose names are associated with the introduction of steam carriages may be mentioned GURNEY, BIRSTAL, TREVITHICK, HANDCOCK, and MASCHERONI. Gurney's vehicle, which was one of the first placed in actual service, completed several very successful journeys, but its progress was arrested by the trustees of the highways, who feared the destruction of their roads, and who adopted questionable means of effecting their purpose. In 1831 a parliamentary committee reported very favourably upon the introduction of steam carriages, and recommended some limitation of the excessive tolls that had been imposed upon them; but some progress had already been made in the introduction of railways, which, it was seen, could be introduced with less opposition and more hope of success.

EARLY LOCOMOTIVES.—In 1804 TREVITHICK and VIVIAN constructed a locomotive which was employed for hauling coal upon the Merthyr Tydvil Colliery railway in South Wales. This engine of Trevithick resembled Murdoch's model in some respects, but it introduced a return flue through the boiler, and to this feature was largely due its success. Later attempts by other engineers, who failed to realize the value of carrying the hot furnace gases through the boiler, were quite unsuccessful. Although the Merthyr Tydvil railway was the first upon which locomotives were employed, it was never used as a passenger line, and although locomotive steam carriages were introduced by GEORGE STEPHENSON, in 1825, on the Stockton and Darlington railway, the first passenger railway chartered by Act of Parliament was the Liverpool and Manchester railway. Before determining the traction system to be adopted upon the line, the directors offered a prize of £500 for the engine which would best fulfil certain conditions of weight, price, and power, and also stipulated that the engine "was to consume its own smoke, and to be able to draw three times its own weight at a speed of 10 miles an hour". Of the five locomotives which were entered, the "Rocket", constructed by Booth and Stephenson, alone satisfied all the requirements, and to them the prize was accordingly awarded. The great success of this locomotive was undoubtedly due to the large heating surface, obtained by introducing fire tubes, which at the present day are an essential feature of all locomotive boilers.

RAILWAY GAUGES.—Railway engineers are severely handicapped at the present day by the smallness of the gauge, which was chosen in the early days as being the width between the wheels of the carts then in use, and was later retained on the score of cheapness. It is now practically impossible to convert to a broader gauge than 4 ft. 8½ in., which would permit of an increase in the powers of locomotives and give greater freedom in their design and in the design of the rolling stock. Prior to 1872, and at intermittent periods thereafter, the relative merits of broad and narrow gauges were the subject of much controversy, but, excepting in the case of the Great Western Railway, which adopted and used for a

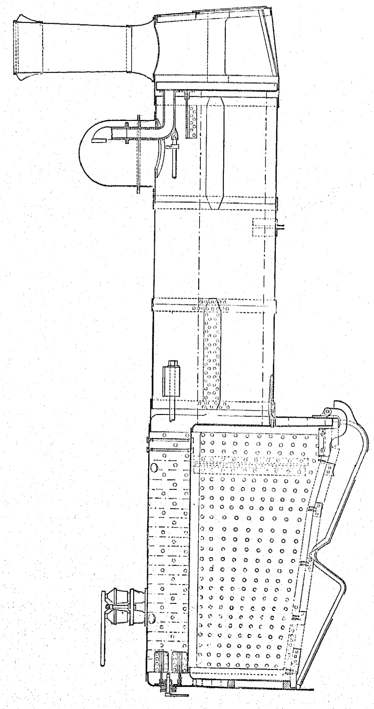


Fig. 548.—Locomotive Boiler (longitudinal section)

considerable time a 7-ft. line, the narrow-gauge railways rapidly extended over the whole country, with the result that it is now very difficult to design single locomotives sufficiently powerful to draw the present-day heavy train loads at the desired high speeds.

THE BOILER.—Whatever the type of a steam locomotive, it may be considered as comprising three essential parts, namely, the frame, which rests upon the wheels and transmits to them the whole weight; the engine and motions carried directly on the frame; and the boiler, supported upon it with some flexibility to permit of longitudinal expansion. This arrangement of carrying all the working parts upon strong side frames relieves the boiler from any severe external stresses, to which it would otherwise be subjected. As the capacity of the boiler really determines the power of the engine, this portion will first be dealt with. From the illustration, fig. 548, it will be seen that the boiler consists of a cylindrical shell, connected at one end to the firebox, in which the combustion of the fuel takes place, and at the other end to the smokebox, upon the top of which is placed the funnel. A large number of tubes traverse the water space of the shell from the firebox to the smokebox, and as the hot gases pass away through them to the chimney, they constitute a valuable extension of the heating surface. Behind the firebox is placed the platform from which the furnace is stoked and the engine controlled, and at the present time one engine driver and one stoker only are generally employed upon the engine footplate.

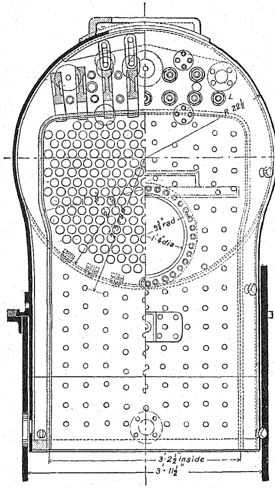


Fig. 549.—Crampton Firebox (cross section)

The firebox consists of an inner rectangular box of copper or steel, with the grate bars at the bottom, and surrounded on the sides and top by a water space, which is the most effective part of the boiler. As

the pressure is generally as much as 175 lb. per square inch, it is necessary to stay the flat sides of the inner box to the strong sides of the outer, as shown in the illustration, and particular care is necessary in supporting the flat roof to prevent all danger of collapse. In the Belpaire arrangement, shown in section in fig 548, the top of the boiler shell is also flat, and the roof of the firebox is directly suspended from it by tiebars, jointed, in the case of the first few rows, to reduce the rigidity, which is one defect of the system as compared with the older Crampton firebox, fig. 549, in which the flat roof of the inner box is suspended from roof bars or bearers resting at their extremities upon the front and back plates. These bearers are necessary, owing to the difficulty of directly suspending the roof from the outer boiler shell, which is curved at the top instead of flat. The Belpaire arrangement provides a larger water space where most required, directly over the fire, and the circulation is not greatly obstructed.

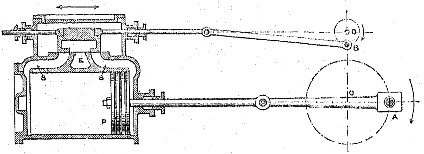


Fig. 550.—Cylinder and Slide-valve Arrangement. The valve is shown without laps or lead

When the nature of the fuel necessitates a very large grate area, as in certain American engines which burn wood, the grate is extended over the frames instead of being carried between them. Boxes of this kind are known as the Wooten type. Smoke tubes serve the double purpose of carrying the gases to the chimney and of greatly increasing the heating surface and, therefore, the steaming capacity of the boiler, but there is a limit to the number that can be used in any particular case, because by decreasing the diameters and increasing the number of the tubes there is danger of seriously affecting the draught and of making the water spaces so small that they become choked with sediment. Upon the careful arrangement of the smokebox depends to a considerable extent the steaming power of the locomotive. It provides some protection for steam pipes which pass through it to the cylinders underneath, and it also prevents the ejection of hot ashes from the funnel under the action of the strong blast induced by the exhaust steam in its passage through the conical blast pipes into the funnel. Baffle plates are generally provided to ensure that the gases will be drawn equally through all the tubes.

Action of the Valve Gear.—Before describing the various arrangements of cylinders adopted, the action of the engine and of the valve gear, or "motion" as it is called, must be again briefly considered. In figs. 550 and 551 are shown the elements of a steam engine, in which

for simplicity the essential parts only are indicated. O A is the engine crank and O B the crank equivalent of the valve eccentric, which in reality is keyed upon the main crank shaft, the point O being therefore common to both. It will be seen from fig. 550 that rotation in the direction of the arrow will cause the valve to admit steam from the valve chest to the right side of the piston P, and that the engine will continue to move in the same direction; whereas, any attempt to rotate the crank in the reverse

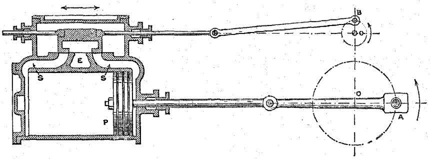


Fig. 551.—Cylinder and Slide-valve Arrangement. The valve is shown without laps or lead

direction would admit steam to the other face of the piston and prevent the backward motion, which could only take place under the conditions illustrated in fig. 551. To obtain a continuous motion of the engine in one direction or the other, it is thus necessary to place the valve eccentric about 90 degrees in advance of the engine crank, and to reverse the motion the eccentric therefore must be displaced about 180 degrees, as shown in the two illustrations. In the Howe valve gear, generally known as the Stephenson link motion, two eccentrics, A and B, are keyed to

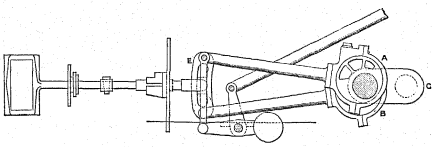


Fig. 552.—Stephenson Link Motion

the shaft in positions about 180 degrees apart, and either one or other is made to control the valve when it is desired to make the engine run forwards or backwards, as the case may be. This is effected, as illustrated in fig. 552, by coupling the eccentrics to the ends of a link E, which engages the end of the valve spindle. By lowering the link, one of the eccentric rods is brought into line with the valve and alone affects its motion, as the only effect of the other eccentric is to idly swing the link. Similarly, by raising the link the other eccentric is brought into operation, and the engine

is caused to run in the opposite direction. When the link is moved into the mid position the motion of the one eccentric neutralizes that of the other, and as the valve is not moved, and no steam is therefore admitted to the cylinder, the engine remains stationary. In intermediate forward or reverse positions the movement of the valve or the point of cut-off is correspondingly affected, and the engine works more or less expansively, which means greater economy of working, although the actual power developed is less. Referring again to the diagram, fig. 550, it will be seen that the slightest displacement of the valve admits steam to the cylinder, and that the expansive force of the steam is not used as the steam enters throughout the stroke. To overcome this objection the outer edges of the valve faces are extended so as to overlap the steam ports. Steam is thus admitted during a portion only of the full travel of the valve, but it is further necessary to set the eccentric more than 90 degrees

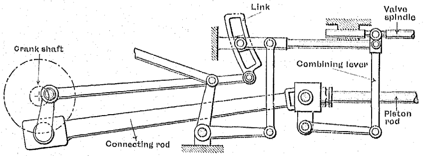


Fig. 553.—Walschaert Valve Motion

in advance of the crank, so that the valve will commence to open just as the piston comes to the end of its stroke. In practice the terms "lap" and "lead" are used to denote the extension of the valve face and the advanced position of the eccentric. The inside exhaust edges are also frequently extended to entrap a portion of the exhaust, which becomes compressed to the pressure of the entering live steam and also assists in eliminating shock at the reversal of the motion of the piston. An objection to the Stephenson link motion is that the lead and lap effects are not constant for all positions of the link, and other arrangements have been extensively adopted, in which one part of the gear alone controls the travel of the valve, while the other controls the lap effects. The Joy, Hackworth, and Walschaert radial gears are all of this type. The Walschaert gear (fig. 553) is very extensively used on the Continent, and its use in this country is also becoming more general.

CYLINDER ARRANGEMENTS.—Owing to the limited width between the engine frames, which is determined by the railway gauge of 4 ft. 8½ in. adopted in this country, it is difficult in the case of powerful locomotives to find sufficient room between the frames for two large-diameter cylinders with their valves and gear; and in such cases the number of cylinders is increased, some being arranged outside the frames and one or two between them. There is the one objection to outside cylinders, that they

cannot be so readily protected from cold air which causes loss through condensation of the steam; but on the other hand, when outside cylinders alone are used, the comparatively weak cranked-axle arrangement can be dispensed with, as the connecting rods then drive the wheels directly. Among locomotive engineers there has been much discussion as to the value of compound expansion, which is greatly favoured on the Continent and in America, but not so generally in this country, although it has strong advocates. Much apparently depends upon the conditions of working, which vary considerably. Thus, for example, American locomotives are called upon to haul heavy loads over long distances, and these uniform and continuous conditions seem to be well satisfied by the use of heavy, four-cylinder, compound expansion engines.

TYPES OF LOCOMOTIVES.—The arrangement and the size of the locomotive wheels largely determine its suitability for a particular service,

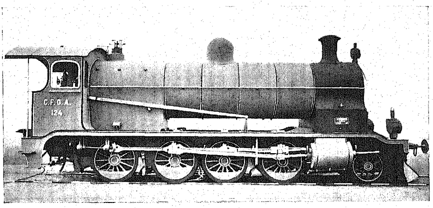


Fig. 554.—Eight-coupled Locomotive for Heavy Goods Traffic

because, since the power is practically limited by the gauge and by the headroom under the tunnels and bridges, an increase of tractive force can only be obtained at the expense of the speed by reducing the wheel diameter. By comparing the two illustrations of the heavy goods engine, fig. 554, and the express passenger locomotive, fig. 555, the characteristic difference of wheel diameter will be clearly seen. To obtain the necessary adhesion upon the rails several pairs of wheels are coupled together in order to utilize the whole weight of the engine, which could not be distributed or carried upon one driving axle. As the most characteristic features of a locomotive are the arrangement and the number of its wheels, upon these are based the several classification systems in common use. In America the different types have for some time been known by particular names, conveying in themselves no definite information regarding the construction; thus, for example, the "Atlantic" type of locomotive, fig. 555, has a leading four-wheel truck followed by two pairs of coupled driving wheels, and at the rear a single radial trailing axle, and in the "Columbia" a single radial axle is substituted for the leading truck.

These names are still generally employed, but recently there has been adopted a numerical notation which specifies not only the number of the coupled and the carrying wheels, but also their arrangement. Three numerals are employed, the first of which shows the number of leading carrying wheels, while the second shows the number of coupled drivers, and the third figure the number of trailing carrying wheels. A locomotive

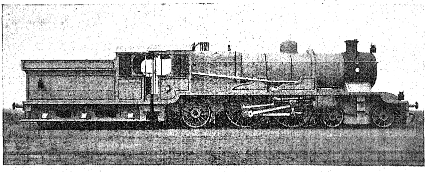


Fig. 555.—Four-coupled Locomotive for Express Passenger Traffic

of the Atlantic type would be represented by the numbers 4-4-2, and the Columbia by the numbers 2-4-2. In the case of the Mogul type, which has one leading pair of wheels and three pairs of coupled drivers but no trailing wheels, the numerical notation would be 2-6-0. Upon the Continent a similar system is occasionally used, but it only gives an indication of the number of coupled axles and the total number of axles. Thus,

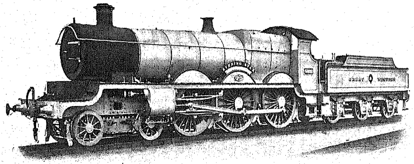


Fig. 556.—Great Western Railway Company Express Passenger Locomotive

instead of the notation 4-4-2, which represents the "Atlantic" type, the numbers 2-5 would be employed upon the Continental system, indicating an engine having two coupled axles and a total of five driving and carrying axles.

Several examples of typical locomotives are illustrated in figs. 554, 555, 556, 557. The first example shows an eight-coupled, 2-8-0, "Consolidation", goods locomotive built for the Anatolian Railway service, and

although the engine is of Continental manufacture it has the neat external appearance which has long been a feature of British locomotives. Outside cylinders have been adopted with the valves and motion arranged between the frames, and the steam is expanded on the compound system so greatly favoured abroad. In fig. 556 is illustrated an express passenger locomotive of the Great Western Railway Company. It has a leading truck and six

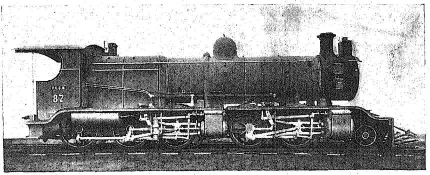


Fig. 557.—Articulated Locomotive

coupled drivers, and it may therefore be described by the numerals 4-6-0. This type of locomotive has an extended smokebox and a tapered boiler, which increases in diameter towards the Belpaire firebox. In fig. 557 is shown an articulated locomotive, built by Messrs. Borsig, of Berlin, for the Great Northern Railway of the Argentine Republic. It will be seen that the front of the boiler rests upon a separate frame of the 2-4-0 type,

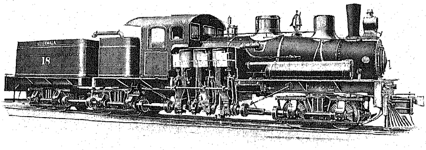


Fig. 558.—Shay Heavy Goods Locomotive

and that the two portions of the articulated frame are driven each by its own set of compound cylinders. Some reference has already been made to the complicated appearance of the Walschaert valve motion, which is noticeable in this particular example. In the direct-connected type of locomotive the wheels are driven by means of bevel gearing directly from the engine shaft, and in the case of the Shay locomotive, built by the Lima Locomotive Company of Ohio, America, the engines are attached in a vertical position at the sides of the boiler, as shown in fig. 558.

ELECTRIC LOCOMOTIVES.—Electric locomotives have been introduced

upon certain local sections of the railway systems in this country, and the electrification of other portions is proceeding, although it is still by no means certain that the economy obtained is sufficient in all cases to warrant the heavy expenditure involved in the conversion to the newer system.

The first electric railway (fig. 559) was installed by Siemens & Halske at the Berlin Exhibition of 1879, but the real commercial developments have all taken place within the twentieth century. In 1899 a series of very interesting experiments was undertaken by two German electrical firms, Messrs. Siemens & Halske and the Allgemeine Elektricitäts-

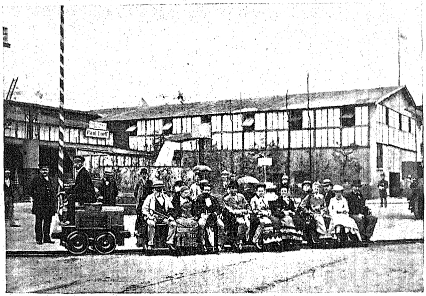


Fig. 559.—The First Electric Passenger Railway, Berlin Exhibition, 1879

Gesellschaft of Berlin, for the purpose of determining the conditions under which very high train speeds might be attained and the best design of the plant. The experiments were carried out upon a comparatively straight military line of 23 km. length, between Marienfelde and Zossen in the neighbourhood of Berlin.

A straight portion of the special track is illustrated in fig. 560, which also shows the three lines of overhead wires used for the transmission of the three-phase currents employed. Each of the two firms concerned constructed cars which, during the latter tests, were run alternately. In the case of the Siemens and Halske car two sets of triple collectors, one collector for each phase, were carried upon masts at the ends of the car as shown in fig. 561, and in the A. E. G. (Allegemeine Elektricitäts-Gesellschaft) design two sets were also provided; but they were carried separately each upon its own spindle (fig. 562). Both arrangements gave complete satisfaction, and proved the possibility of picking

up the current from trolley wires, even at the highest attainable speeds. During the trials run in the autumn of 1901 speeds as high as ninety-three miles per hour were frequently maintained, but owing to the excessive oscillations and shocks experienced it was thought advisable to rebuild the track before continuing the tests at higher speeds. Towards the end of 1902 the trials were continued on the new permanent way, and

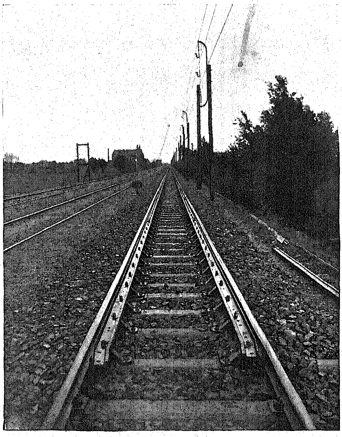


Fig. 560.—Portion of the Berlin-Zossen Experimental Track

the very high speed of 130 miles was attained on one section of the line.

These experiments give some indication of what may be done in the future, when the conditions permit of the general introduction of high-speed electric railways. Many of the railroads which were first converted to electric traction were supplied with three-phase current, as in the case of the later Berlin-Zossen experimental line, but single-phase installations are now very generally favoured in America and throughout the Continent, and many of the most recent railroad installations are of this type. In the case of three-phase systems a very complicated and expensive trolley

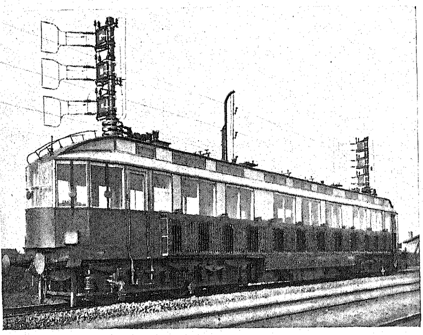


Fig. 561.—The Siemens & Halske Experimental Car

line is required, as will be seen from the examples given of the Berlin-Zossen line, and for these and other reasons it is probable that the

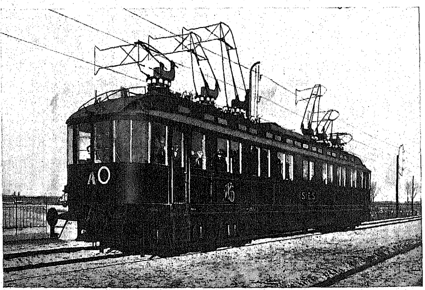


Fig. 562.—The A. E. G. Experimental Car

single-phase line will come still more into favour for railroad-traction purposes.

A typical electric locomotive, built by Messrs. Siemens and Halske, for the Berlin-Zossen Railway, is illustrated in fig. 563. As has been already mentioned this experimental line is supplied with three-phase alternating current, the pressure being 10,000 volts. The locomotive illustrated is equipped with two motors of 350 e.h.p., the total power being 700 e.h.p. It will be seen that, compared with a steam locomotive, the question of design is a simple one. The two trucks are arranged

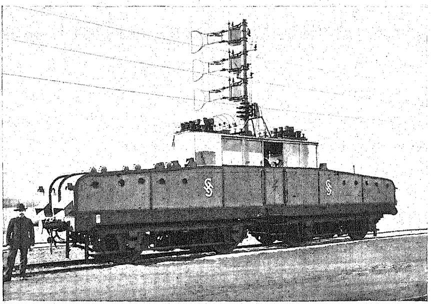


Fig. 563.—Electric Locomotive of 700 e.h.p.

symmetrically, and each axle carries an equal portion of the weight, which is thus evenly distributed over the rails.

LOCAL RAILWAYS.—The system of railway communication which has become universal provides a rapid and convenient means of transport between the principal centres of the country; but, owing to the expensive character of the track, and to the impossibility of carrying the lines wherever desired, some more flexible network of communications is necessary to collect the traffic and to form a connection with the main lines. In the case of a city, therefore, the secondary communications take the form of local lines, which deal with local and suburban railway traffic, and of street tramways, which pick up passengers at all parts of the routes along which the lines are laid.

Suburban traffic is generally of a light nature, and as the stoppages are frequent a specially light type of locomotive is employed. In this way the time occupied in stopping and accelerating the train after each stoppage

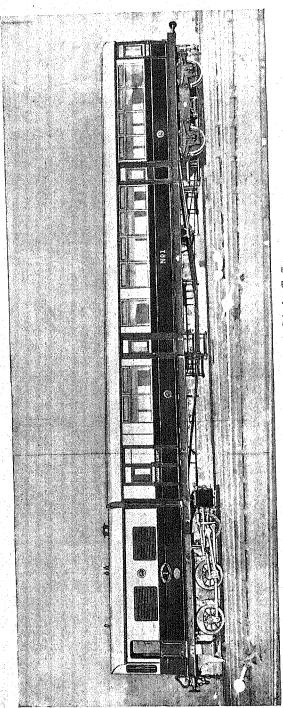


Fig. 564.—Steam Railway Car for Suburban Traffic

is reduced, and the efficiency of the service is thereby improved. Until within recent years each suburban train was composed of a number of coaches, the weight of which was very considerable compared with the weight of the traffic carried, especially at slack periods of the day; but upon many of the local lines throughout the country it is now customary to run single cars at more frequent intervals to meet the requirements of the service.

One such car is illustrated in fig. 564, from which it will be seen that the car is rigidly attached to the locomotive, the necessary flexibility of the wheel base being obtained by supporting the rear end of the car upon a truck permitting of a considerable side motion of the car body. Upon the lines that have been electrified, electric motor cars of a similar character are also very generally employed, and as the competition of the street tramways continues to increase it is probable that the use of such cars will be further extended.

CHAPTER X

TRAMWAYS AND MONO-RAILS

STREET TRAMWAYS

HORSE TRAMWAYS.—Street tramways for passenger traffic have the great advantage that by running directly through the thoroughfares they carry the passengers nearer to their destination, whereas the local railway only conveys them to a comparatively limited number of stations; but, on the other hand, the frequent stoppages and the necessarily slow speed are against the tramway as compared with the local railway when the service upon the latter is maintained under good conditions. Very many systems of tramways have been, and still are, in use at the present time, but horse traction, the earliest of all the systems, may now be considered as entirely obsolete. So far as the track and the equipment are concerned, the horse system is the cheapest; but the cost of working is high, and the speed is limited to at the most 5 or 6 miles in the suburbs. Under these conditions the horse car cannot successfully compete with local railway systems. Apart from the humanitarian aspect of the question, the removal of the horses from the streets has resulted in a considerable economy in the cleansing of the tracks, with an improvement of the sanitary conditions.

STEAM AND GAS TRAMWAYS.—Steam traction can be readily substituted for horse traction without any costly alteration of the permanent way, and without the installation of new plant other than the locomotives and new rolling stock. Steam cars are, however, objectionable on account of the noise, and of the smoke and steam emitted, although by the adoption of condensers the latter objections may to some extent be overcome.

Before the introduction of electric traction, steam tramways were freqently installed; but few examples now remain, and it is doubtful if the system is capable of being sufficiently improved to enable it to compete with the very convenient systems of electric traction now in general use.

Gas-driven cars have also in the past been installed in several districts where the price of gas is moderate, but the disadvantages are too numerous to permit of their general use. To any form of street locomotive, whether steam, gas, or oil, there are objections on the score of disagreeable noise and smell, and electrical systems are preferable from every point of view.

CABLE TRAMWAYS.—Cable traction involves a very special form of track, and it is therefore costly to convert an ordinary existing track. Between the rails there is placed an underground conduit through which the cable runs continuously, suitable grooved pulleys being provided to carry the cable and to guide it around curves. From the bottom of the car there projects into the conduit through the surface slot a grip, the jaws of which can be made to grip the cable by means of a handwheel placed within the control of the driver. By loosening the grip the jaws are caused to release the cable, and the car can then be stopped or allowed to run freely; and when the jaws are closed the car is hauled at the speed of the cable, which is definite and cannot be readily changed without the general

introduction of auxiliary cables. This fixed maximum speed is one objection to the system, especially on city and suburban routes, where the low speed necessary in the crowded thoroughfares is inconveniently low for the outlying districts. For continuous circular routes with few crossings the system is a very economical one, and the suitability of the arrangement under such simple conditions has been well proved in the case of the Brooklyn Bridge cable system and in certain underground cable railways. When, however, there are numerous crossings the underground arrangements become very complicated, and the possibility of one or more routes becoming blocked through the carelessness of one of the many car drivers is considerable. When approaching a crossing it is necessary for the driver to disengage his grip from the cable, and, after passing the junction under the momentum of the car, to again grip the cable. In the case of long crossings, or where it is impossible to run over without stopping, auxiliary cables, running at a slower speed, are provided. These cables are driven by the main ones at the required slow speed, and they are carried upon pulleys which can be swung either by hand or automatically so as to bring the auxiliary into line with the main cable when desired.

Owing to the inherent faults of the cable system for tramway purposes, and to the frequent breakdowns that occur as a result of the stranding of the steel rope and the blocking of the slot, it is doubtful if the method will be again adopted in an entirely new installation.

Electric Accumulator Cars.—Of the many electrical systems that have been introduced, the simplest, so far as the cost of permanent-way construction is concerned, is the electric accumulator car. No overhead or underground wires are required, and no alteration of existing tracks is involved, so that the system is particularly suited to city and other districts where the erection of unsightly overhead wires is an objection, and where the heavy initial cost of installing an underground system cannot be contemplated. Accumulators are unfortunately very heavy, being composed almost entirely of lead plates, and they constitute a considerable portion of the total running weight. The working conditions are also of the worst description, as the plates are subjected to severe shocks and vibration, while the frequent and heavy discharges of current which take place when the car is started under a heavy load or on a hill seriously reduce the life of the cells. When shunt motors are employed, the energy of the car when descending hills can be utilized for recharging the accumulator by making the motor act as a dynamo. In this way the speed of the car is prevented from increasing, while at the same time the accumulators receive a good recharge after climbing a hill.

At each terminus provision is sometimes made for recharging the cells while the car is waiting previously to the return journey, but, as the time is limited, this generally necessitates a very heavy charging current. To overcome this objection, the accumulators are frequently carried in a frame which can be readily removed at the end of the journey, a new set of charged accumulators being substituted for the discharged one. The accumulator system has been adopted in sections of certain large cities, in conjunction with the trolley system, the latter being used only in the

suburban districts where the presence of side poles and overhead wires is not a serious objection. With a combined system of this kind the accumulators are charged through the trolley from the overhead wire while the car is running through the suburbs, and when the city portion of the road is reached the trolley is drawn down and the motors are then driven from the storage cells.

OVERHEAD TROLLEY CARS.—In the various other electrical systems commonly employed a considerable amount of gear is required in addition to the track rails, and the cost of the installation is therefore considerable. In the overhead trolley system the current is supplied to overhead wires

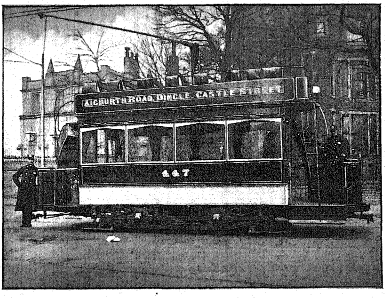


Fig. 565.—Typical Double-deck Electric Car for Overhead Trolley System

suspended at a sufficient height above the track, and the current is conveyed to the car through a trolley pole, the wheel of which runs pressed against the wire by means of strong springs (fig. 565). Sometimes the wheel is dispensed with, and a sliding contact is used instead.

Most frequently the current, after its passage through the motors, is conveyed back to the generating station through the car wheels, and thence through the rails, which must therefore be continuous. If a bad joint exists anywhere on the line, the current, in finding its way back to the station along the path of least resistance, will probably pass through adjoining water and gas pipes, in which case serious corrosion, due to electrolysis, is induced at the points where the current enters and leaves them. This difficulty can best be obviated by making the resistance of the rails as small as possible, and many arrangements have been devised for connecting the ends of the rails together either by welding or by means of copper bonds. Rail returns are sometimes dispensed with and a second

overhead return substituted, in which case there are provided two trolleys. In the Leeds railless tramway system there are two overhead trolley cables, and the cars run upon ordinary roads not provided with rails. Although the overhead wires are unsightly, the single-wire system is a convenient and inexpensive one, and it has the advantage of being less permanent than the more costly conduit systems, which, once installed, could only be converted at a great loss.

CONDUIT TRAMWAYS.—To some extent the conduit electrical system resembles the cable-traction system already referred to, but the grip merely

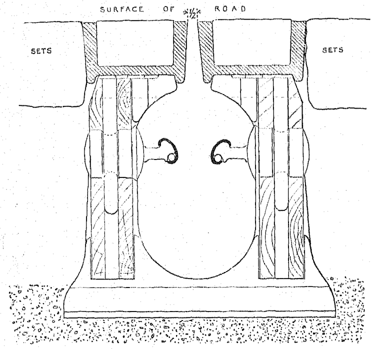


Fig. 566.—Transverse Section of Conduit of Electric Tramway System

rubs upon the underground wire, which is stationary, and only carries the current (fig. 566). As in the overhead system, one conductor may be used, in which case the rails serve as the return wire, or two conductors insulated from one another may be employed, to obviate the necessity for an earthed return; but this arrangement is not a common one.

There are many difficulties, which can only be partially overcome, and of these the most serious is the difficulty of maintaining the insulation of the exposed high-tension wires. Water and mud find their way through the surface slot into the conduit, and cause serious leakage of current and electrolysis of neighbouring pipes. For this reason, wherever a conduit system is installed, it is necessary to make ample arrangements for draining away storm water, and this increases the cost of the installation.

SURFACE-CONTACT ELECTRIC TRAMWAYS.—Surface-contact or closed-

conduit systems, in which the parts are entirely enclosed and protected from moisture, have been installed in various districts, as, for example, in Wolverhampton; but the results expected have not been in practice wholly realized, owing to the difficulty of maintaining the numerous street contact boxes in sufficiently good condition. In a surface-contact installation the current is supplied to studs placed between the rails at intervals of less than the length of the car, and which project slightly above the road surface. On the under side of the car is arranged a long collector bar of sufficient length to bridge the distance between the two studs, and thus to be always in contact with at least one stud, from which the supply of current is drawn. If, however, the studs were permanently connected to the conductors there would be great danger to the public, and it is therefore necessary to provide means for automatically making the

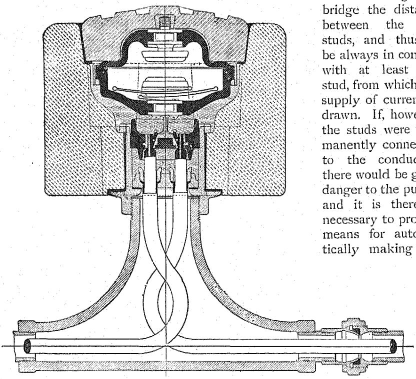


Fig. 567.—Lorain Surface-contact System—Longitudinal Section of Contact-box

consecutive studs "live" as the car reaches them, and for again making them "dead" by cutting off the current as the car leaves them. This is effected in the Lorain surface-contact system, as installed at Wolverhampton, by means of electromagnets on the cars, which attract armatures in the stud boxes as the car passes over them, and thus connect the surface contacts with the supply mains. When a car has passed a stud, the armature in it falls by gravity and makes the surface contact dead. A longitudinal section of a street stud box is shown in fig. 567, and the action of the car magnet is illustrated in fig. 568, which shows the magnet in position over a box. From these drawings it will be seen that the box contains only one moving part, namely, the soft-iron disc or armature to which the carbon

contact E is attached, and that the essential parts are entirely enclosed. As the car magnet bars F F′, which run from end to end of the car, pass over a box they attract its armature A A′ and raise it until the carbon block E comes into contact with the carbon contact D, thus placing the manganese steel stud O in connection with the supply mains through the flexible copper strip E′, shown in side view in fig. 568. All the spaces T T T around the box are filled with insulating oil, which prevents moisture from creeping along the cable connections into the interior of the box. Magnets are arranged at intervals along the car, and their similar poles

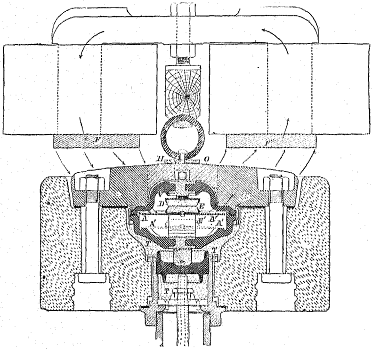


Fig. 568.—Section of Contact-box, Contact-shoe, and Magnet System on Car

are connected to the pole shoes F F′, which thus keep the box armatures in the attracted position until the car has passed over them. The collector bar or shoe H, which rubs upon the stud and collects the current, is arranged between the pole shoes, as shown at fig. 568, and the magnet shoes are prolonged at each end beyond the current-collecting shoe, so that each stud becomes live before the collector actually comes in contact with it, and becomes dead only after the collector has left it. This arrangement prevents all possibility of arcing at the carbon circuit maker within the boxes, as the interruption of the current then only occurs between the studs and the collector as it comes into contact with and leaves them.

In practice some difficulty has been experienced in maintaining the insulation of the numerous boxes, and accidents have occurred through

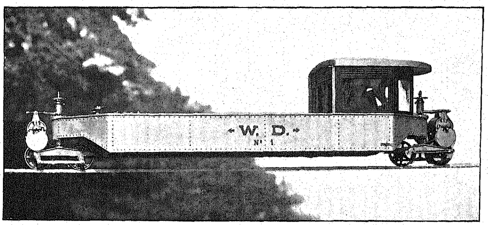
the failure of the armature to fall after the car has passed, with the result that the stud remains live and becomes a source of serious danger to foot passengers and horses. In other surface-contact systems the use of car magnets is dispensed with, and the fall of the contact block within the stud, immediately the flow of current is interrupted by the passage of the collector, is made to operate electrically the contact maker in the box ahead of the car. This system involves the use of considerable mechanism in conection with the various studs, and to facilitate inspection and repair the mechanisms have been grouped together in section boxes at the sides of the tracks, where they are readily accessible, instead of in the individual boxes, where their supervision would be very difficult; but even with this arrangement the objections to the system have not been entirely overcome.

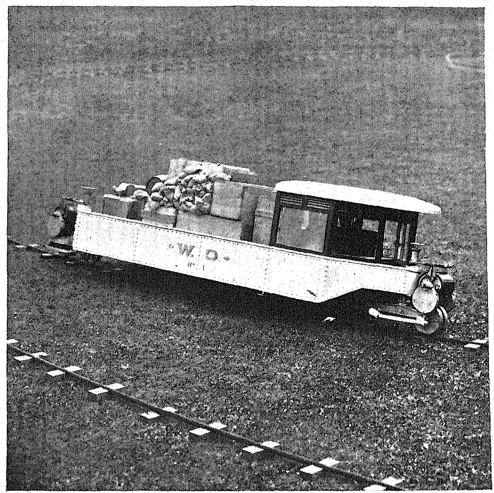
THIRD-RAIL SYSTEM.—Where the track is not laid upon the public streets, and where it is sufficiently protected from foot passengers, the third-rail system is frequently adopted in preference to the overhead conductor, which involves a more costly superstructure for carrying the wire. In the third-rail system a conducting rail is carried upon suitable insulators at the ground level, either between the track rails or more frequently at one side, and the train or car is provided with shoes, which slide in contact with the conductor and pick up the current from it. Two picking-up shoes are generally provided, one at each end of the car, the distance between them being sufficient to enable them to bridge over the gaps in the conductor rail at crossings and junctions where it is impracticable to make the rail continuous.

MONO-RAIL TRACTION SYSTEMS

GENERAL CHARACTER.—The mono-rail system of carrying the carriages upon a single set of wheels placed in line under them has been applied in a few unimportant cases—as, for example, in the north of Ireland—and it has been proposed upon a larger scale by Mr. Behr for a main high-speed passenger line between Manchester and Liverpool. Although parliamentary sanction was obtained long ago, the scheme has not been carried into effect, owing principally to financial considerations. In the mono-rail system the track is built of A frames, upon the top rail of which run the carriage wheels. The cars thus sit astride of the frames, and at the foot on either side are arranged guide wheels which prevent any serious sidewise rocking, and which come into action more particularly when running round curves. In the Irish line already referred to the locomotives employed have two boilers, placed one on each side of the frames, and in this way the centre of gravity of the moving mass is not far above the top rail level. At junctions it is necessary to move a section of the trestles into line with the branch upon which it is desired to run the train, and as this is a very cumbersome operation, the use of the mono-rail system for heavy express traffic is practically restricted to direct lines of the proposed Manchester-Liverpool type, over which the trains were intended to be run without intermediate stops.

Brennan Mono-rail.—By an ingenious application of the Foucault gyrostat, Mr. Louis Brennan has succeeded in constructing a car which is capable of running upon a single rail, and which does not require to be controlled by means of guide wheels when running round curves. From the two illustrations of the working model first constructed it will be seen that in the one case the car is running round a curve upon a single track of the simplest description (see the Plate), while in the other the car is shown standing upon a steel cable stretched at some distance above the ground. Each end of the carriage is supported upon a pair of wheels placed in line and driven by motors, the current for which is supplied in this particular example by accumulators carried upon the car, but any suitable driving system might be adopted in practice. The essential feature of the invention is the application of the gyrostats, which prevent the car from falling over when it is not moving, and which enable the car to safely run over sharp curves by automatically causing it to incline inwards towards the centre of the curve by an amount sufficient to maintain stability. This tilting over of the car is clearly indicated in the Plate, and it will be seen that, as in ordinary railway practice, it is necessary to give the track the super-elevation determined by the radius of the curve and the normal speed of running. A gyrostat of the simplest kind consists of a flywheel, which is spun upon its axis at a high speed, and such an arrangement tends to maintain the direction of its axis of rotation. Thus, for example, the rifling of a gun barrel is designed to produce a rapid rotation of the bullet, and in this way to preserve the direction of its motion. If a gyrostat mounted in a frame be suspended within a gimbal having its two axes arranged at right angles to one another and to the axis of the rotating wheel, it will be found that any attempt to swing the frame, and with it the spinning wheel, about one of the gimbal axes is strongly resisted, and that a constant rotation about the other axis of the gimbal in a plane at right angles to the applied couple is introduced. In the Brennan arrangement the axis of the outer gimbal ring is carried in bearings attached to the car body, and the gyrostat wheel is spun by electrical means at a speed of several thousand revolutions per minute, depending upon the relative weights and dimensions of the car and wheel. Upon the extended spindle of the wheel is carried a roller, which in the normal position runs freely between an upper and a lower guide plate. A similar roller, capable of rotation about the same axis, but carried upon the inner gimbal frame, also runs freely between two similar guide plates. When the car swings over under the action, for example, of a gust of wind, the spindle of the gyrostat maintains its original direction relatively to the earth, and the upper guide, which moves with the car, then comes into contact with the roller on the spindle of the gyrostat, and the tilting movement is arrested. At the same time the friction of the roller on the guide introduces a tangential force which causes the gyrostat to swing upwards, carrying with it the guide plate, and therefore the car to which it is attached. If the car rises under the action of the gyrostat against the wind, and swings over too far, the second roller comes into contact with





THE BRENNAN GYROSCOPICALLY CONTROLLED MONO-RAIL CAR

a fixed lower guide and the motion is stopped; but, as this roller is carried upon the frame, no precessional motion is introduced, and the frame is not in consequence caused to swing down again. In this way the car again assumes a stable position with the rollers in the mid position between the guides. To enable the car to move round a curve without carrying the guide plates beyond the mid position, in which they control the spindle, Mr. Brennan has neutralized the horizontal effects of the gyrostat by suitably coupling together two sets, the wheels of which are caused to rotate at equal speeds in opposite directions. The horizontal direction of the axes of the coupled gyrostats then remains constant relatively to the car instead of to the earth, as in the case of a single gyrostat, and they offer no resistance to the car when rounding a curve. As the stability of the car, both when standing still and when running, is wholly dependent upon the continuous rotation of the gyrostat wheels, special precautions are taken to ensure that they will run for a considerable time without being driven, and in the example illustrated the flywheels are for this reason hermetically enclosed in an evacuated chamber and are capable of running alone for several hours.

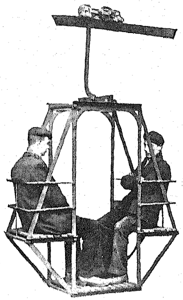


Fig. 569.—Overhead Cableway Passenger Car

OVERHEAD CABLEWAYS.—Overhead cableways are very commonly employed for transporting materials over considerable distances, and in at least one instance for the carriage of passengers. So far they have been used chiefly in mining districts for the carriage of ores from the mines to the mills, where these are situated at some distance away, and they are also extensively used in Ceylon and India for conveying tea leaf. Several systems of wire ropeways are in common use, and the choice of one or the other is determined by such circumstances as the nature of the country, particularly as regards the steepness of the inclines and the length of the spans, and upon the quantity of material to be conveyed. In the simplest arrangement, commonly known as a "SHOOT", a single cable is stretched from high-lying ground to a low level, and the material, which may be sheaves of wheat, is allowed to glide down the rope by gravity. In such cases the runners to which the sheaves are attached are made of the lightest possible construction, so that they may be carried back in numbers to the upper terminal. Where the country is comparatively level an endless running rope, upon which the buckets are carried continuously, is generally employed, and in cases where the inclines are not steep the buckets or carriers are not directly fixed to the rope, but hang from it, and are carried along by the friction of the contact. Carriers of this description are illustrated in

figs. 569 and 570. At the side of the saddle are attached two small wheels, by means of which the carrier may be switched to another line, or shunted for the purpose of loading or discharging when the carriers are used for transporting materials. In such cases the branch rail is slightly inclined, so that when the wheels reach it the momentum of the carrier is sufficient to cause it to run up the incline and raise the saddle completely free of the rope. Running ropes of the kind described may

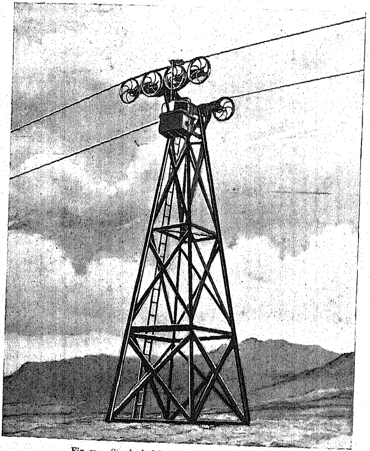


Fig. 570.—Standard of Overhead Running-Cable System

be used, even when the line has to be carried over considerable elevations, by placing guide pulleys above the rope to prevent it from being raised off the supporting pulleys. As a carrier approaches a guide of this kind the weight causes the rope to sag until it rests in the lower pulley, and the carrier is then able to pass freely under the guide wheel.

When the inclines or spans are too great to permit of the use of a running rope which merely rests in the pulleys, fixed ropes are used, and the carriers are hauled by a separate endless running rope to which they are attached by means of clips, which permit of the car being disengaged

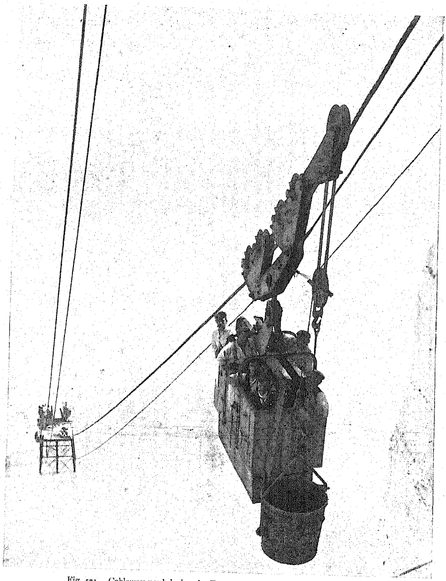


Fig. 571.—Cableway used during the Erection of the Beachy Head Lighthouse

for loading or discharging. At each trestle are provided V guides and a lower guide wheel, upon which the hauling rope runs when the carriers are not passing the trestles. An example of one of the many applications of these cableways is illustrated by fig. 571, which shows its use for the transport of workmen and materials to the Beachy Head lighthouse when under construction.

Means are provided at one or other of the terminals of a cableway for taking up the slack of the rope, the other end being securely anchored.

In the case of the fixed-rope system there are generally two independent parallel ropes anchored at both ends, but provided with tackle for taking up any slackness that may arise from the stretching of the rope. The hauling rope, on the other hand, is continuous, and to keep it sufficiently taut one or other of the terminal pulleys around which it passes is carried upon a tension truck, to which a heavy pulling weight is attached. The driving of the hauling rope is then done by means of the turning pulley at the other terminal. Similar arrangements are provided at the terminals of the endless running ropeway for anchoring the one pulley, and for applying a suitable tension at the other.

CHAPTER XI

MOTOR VEHICLES: PETROL MOTOR CARS—STEAM MOTOR CARS—ELECTRIC MOTOR CARS

INTRODUCTORY.—Within very recent years the traffic upon the public highways has greatly increased, owing to the great development of self-propelled vehicles that has taken place. Before the general introduction of the railway locomotive many attempts were made to run steam-driven carriages upon the highways without the use of rails, and the results obtained were in some cases of a very promising nature, but the opposition of the trustees of the public roads, and of the powerful coach proprietors, and to some extent the engineering difficulties that had to be overcome, resulted in the early abandonment of the various schemes. There is, however, little doubt that under fair conditions steam carriages would have been rapidly brought to a condition of practical usefulness by the engineers interested in their development, and that, as a result of the use of the roads, the transport systems of the present day would have been of a more perfect nature. From 1830, when the Liverpool and Manchester passenger railway was first opened, may be dated the abandonment of all real attempts to introduce self-propelled carriages, and it is only within recent years that the progress of engineering and the change of conditions have made their re-introduction possible.

TYPES OF MOTOR CARS.—Motor cars of the present day are in the great majority of cases propelled by engines of the internal-combustion type, in which the vapours of the lighter classes of oils, such as petrol and light naphtha, are consumed; but there are also several successful cars propelled by steam. Electrically-driven cars were favoured for a time, but at the present day their use is restricted to town areas where the cost of running them is a secondary consideration, and where the surfaces of roads are not irregular. There are thus three general methods of propelling motor cars, namely, by means of petrol or spirit vapour, by steam, and by electric motors; but for many reasons the first system has been adopted by the majority of the manufacturers for all but the heaviest classes of com-

mercial vehicles, which are very frequently propelled by steam. A combination of the petrol and electric systems has been proposed for heavy vehicles, with a view to combining the advantages of both, as neither alone is entirely satisfactory.

As compared with the steam engine, the internal-combustion motor suffers from the great disadvantages inherent in the use of the four-stroke cycle, which in a single-acting cylinder permits of only one working stroke in four, and in the necessity for gear boxes by means of which the running speed of the car may be altered. A steam-driven car involves the use of a steam generator and of burners for vaporizing the water, but it has the great advantage of superior flexibility, as the speed of the engine itself may be altered within wide limits without the use of any gear wheels, and the power developed may also be largely increased as desired, by varying the quantity of steam admitted to the cylinder during each stroke of the piston.

Electric cars involve the use of heavy accumulators usually constructed of lead plates. These accumulators rapidly deteriorate when used under the conditions ordinarily met with in motor-car running more especially in rough and hilly districts, where the vibration and the frequent heavy demands for current cause the plates to shed the active pastes with which their interstices are filled. Apart from this very serious objection the electrical system is ideal both from the point of view of flexibility of power and of the ease with which the speed of the motor may be controlled.

PETROL MOTOR CARS

TYPICAL CAR BODIES.—A motor car consists of two distinct portions, the body and the chassis, which are very frequently built by different

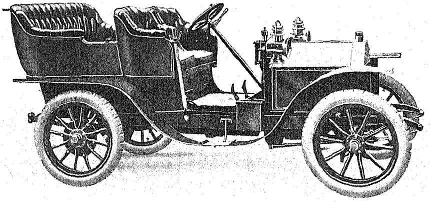


Fig. 572.—Motor Car Tonneau Body

manufacturers, who specialize in the construction of these particular parts. The body comprises all the coachwork, and, as it is this portion which primarily concerns the user, there is a wide variety of types combining

comfort and neatness. Any type of body may, in general, be fitted to a particular type of chassis to meet the wishes of individuals, but there

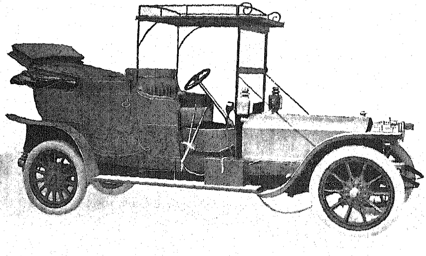


Fig. 573.—Typical Landaulette Body

are now certain recognized forms which experience has shown to be best suited to the average requirements. In the old tonneau arrangement, illustrated in fig. 572, the inside seats are generally only accessible from

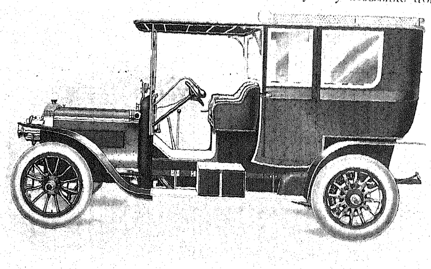


Fig. 574.—Typical Limousine Body

the roadway, and the majority of cars are now arranged with side entrances (fig. 573), which enable the passengers to alight upon the pavement. Fig. 573 represents a typical landaulette body, and the Limousine form, which resembles a closed carriage, is illustrated in fig. 574.

THE CHASSIS.—Under the term chassis is included all the mechanical portions, such as the engine and driving gear, together with the frame and wheels, and it is this portion which more particularly characterizes as a whole the type or make of a car. There are two distinct classes of chassis, which differ in the method of communicating the driving motion to the wheels. In the CHAIN-DRIVE SYSTEM (figs. 575 and 576) the motion is

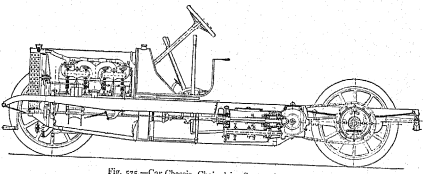


Fig. 575.—Car Chassis, Chain-drive System (elevation)

communicated to the driving wheels by means of chains, while in the other system the rear axle is driven more positively by means of a shaft generally known as a CARDAN SHAFT. From the illustrations it will be seen that the parts are carried upon a strong rectangular frame of U-section pressed steel, from which the load is transmitted through springs to the wheel axles. At the front end is generally placed the radiator or water cooler, and behind it is the engine, which is so

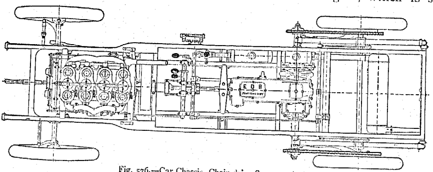


Fig. 576.—Car Chassis, Chain-drive System (plan)

arranged that the shaft lies along the length of the frame. This arrangement of the radiator in front of the engine is, however, not universal. When in running condition a hood covers the engine, but to prevent an undue rise of temperature a free circulation of air is permitted, and in addition there is provided an engine-driven fan which maintains the circulation of cold air over the engine and through the radiator. On the end of the engine shaft is placed a clutch disc, which serves also as a flywheel and as a brake drum, and the corresponding half of the clutch is attached to the transmission shaft, which communicates the motion through the

gear box, by means of which the driving speed and force may be changed while the speed of the engine remains constant. Up to this point there is no essential difference between the cardan-shaft and chain-driven systems, as will be seen by comparing the illustrations. In the chain system the motion is transmitted from the gear box through a differential gear to the chain axle, and thence by means of chains to the wheels, while in the

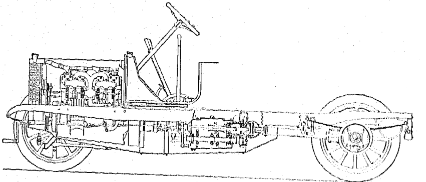


Fig. 577.—Car Chassis, Cardan Shaft System (elevation)

case of the direct-drive system the motion is communicated directly from the gear box through the cardan shaft to the differential connecting the two halves of the rear axle, and thence to the wheels. As in this case the rear axle rotates and transmits the drive to the wheels, it is generally known as a live axle.

This sequence of parts is common to most motor cars, but the arrangement varies in the different types. Thus, for example, the gear box and

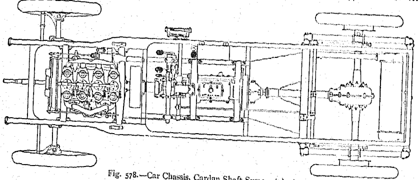


Fig. 578.—Car Chassis, Cardan Shaft System (plan)

brake drum may be embodied in the engine casting, or the gear box may be enclosed in a separate case or combined with the differential gear.

THE MOTOR.—In an internal-combustion engine, such as is adopted for motor-car purposes, the working substance used is spirit vapour, which explodes or burns with extreme rapidity when mixed with the correct proportion of air and then ignited. As a result of the high temperature of the combustion a large increase in the volume of the gases takes place, but

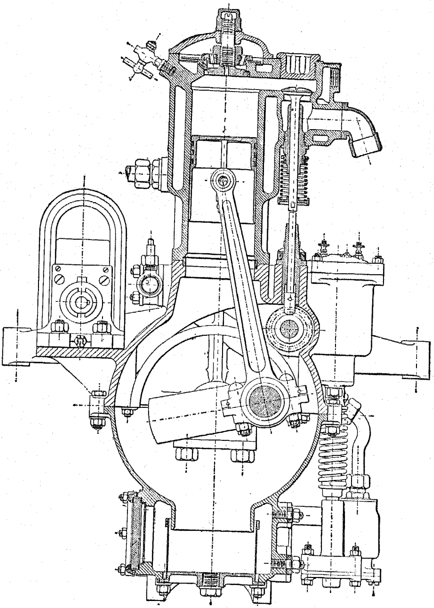


Fig. 579.—Dion-Bouton Petrol Engine (cross section)

as the space behind the piston in which they are generated is small, the pressure of the gas is great and the piston is forcibly driven forward. At the end of the working stroke the cylinder is filled with the inert expanded gas, which cannot be removed as in the case of steam by allowing it to escape to the atmosphere or by exhausting into a special condenser, but which must be driven out of the cylinder during the return stroke of the

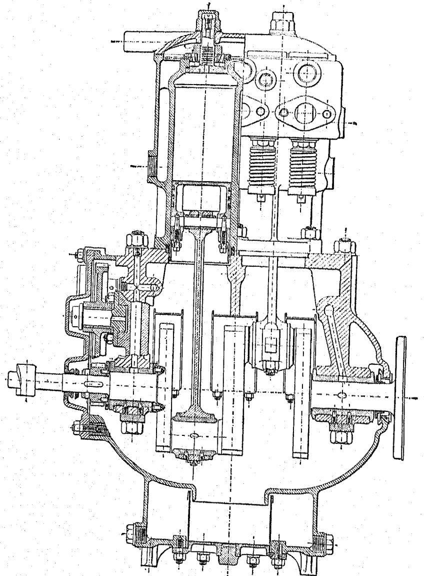


Fig. 580 Dion-Bouton Two-cylinder Engine (part sectional elevation)

piston. It is then necessary to draw in the next charge of vapour and air, and this is done throughout the third stroke of the cycle. During the fourth stroke the piston returns and compresses the mixture into the small combustion space, where it is ignited. By the evolution of the gas in a small space the initial pressure obtained is many times greater than if the mixture had been ignited under less compression, as would have been the case if it had been ignited at, say, the middle of the third stroke.

When the engine is composed of only one cylinder, sufficient power

must be developed during one stroke not only to drive the car during that stroke, but also to impart sufficient momentum to drive it during the three following strokes, and in a single-cylinder car a flywheel of a considerable size is necessary. By the use of two cylinders the working strokes and idle strokes are caused to occur alternately—that is, there is one driving stroke per revolution of the crank shaft—and by duplicating the cylinders, without however reducing their size, the available power is doubled. In the same way, by the use of four of the same cylinders, not only is the power of the motor increased, but the uniformity of the motion is also improved, as there is one impulse at every stroke. Each cylinder is provided with its own valves for controlling the admission of the mixture and the exhaust of the waste gases, and an engine having two or more

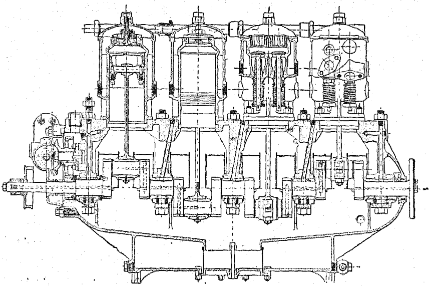


Fig. 581.—Four-cylinder Petrol Engine (sectional elevation)

cylinders may be considered as consisting of two or more engines driving a common shaft.

From the section of the Dion-Bouton engine illustrated in figs. 579 and 580, the action of the various parts will be readily understood. The suction and exhaust valves are opened and closed at the correct intervals by means of cams carried upon a half-time shaft, which rotates at half the speed of the engine shaft, but in some cases the suction valve acts automatically and is not positively driven. One revolution of the cam shaft is equivalent to two of the crank shaft, and each of the valves is thus operated once during four strokes of the piston, as required for the Otto cycle. Valveless engines, such as the Silent Knight engine, have been introduced, in which reciprocating cylindrical liners, pierced by suitable ports, are substituted for the ordinary valves.

In the two-cylinder engine shown, since the cranks are placed 180 degrees apart, the inertia forces are practically balanced, but the turning

motion is less uniform, as the working strokes occur consecutively. When, on the other hand, the cranks are set together, the reciprocating parts move to and fro as one piece, and the forces tending to produce vibration are not balanced, but the explosions occur alternately—that is, there is one working stroke at each rotation of the crank. In the four-cylinder engine, shown in longitudinal section in fig. 581, the arrangement of the cranks is such that the inertia forces are balanced, and when the explosions take place in the cylinders in the order 1, 2, 4, 3, the working strokes occur at regular intervals of half a revolution. From the sections it will be seen that the cranks are entirely enclosed in a case, the bottom portion of which is filled with oil, into which the cranks dip as they revolve. Lubrication of the main bearings is effected by means of a special oil pump, which also supplies oil to the crank-pin bushes through channels bored in the shaft and in the webs and pins of the cranks. As the heat generated at each explosion is very great, it is necessary to maintain a circulation of cold water around all parts acted upon by the hottest gases—that is, the working portions of the cylinders and the valve chambers. Water is continuously circulated by means of a simple valveless pump through the various water jackets, where it absorbs heat from the cylinder walls, and then to the radiator, which is provided with a large cooling surface for the dissipation of the heat to the atmosphere. The cooled water is then available for use again in the jackets.

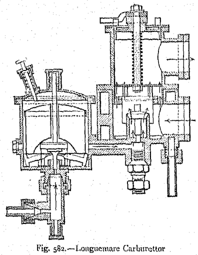


Fig. 582.—Longuemare Carburettor

CARBURETTORS.—Until the spirit fuel is mixed with sufficient air for its combustion no explosion can take place in the cylinder, and means must therefore be provided for supplying the petrol and the air in the correct proportions, and for intimately mixing them so that each globule of the vapour is surrounded by a layer of air. There are many varieties of curburettors which serve to produce the explosive charge, but of these only one typical example will be illustrated. Oil flows either by gravity or under pressure from the supply tank to the float chamber shown in section at the left of the illustration (fig. 582), and its admission is controlled by means of the float and needle valve, which maintain a constant level of oil in the chamber. At each suction stroke a certain quantity of oil is sucked from the float tank through the carburettor jet or valve into the cylinder, but at its exit from the carburettor nozzle the jet of oil becomes broken up in contact with the stream of air which is simultaneously drawn in, preferably over some heated portion of the system. Provision is commonly made for varying the proportion of air, and most frequently the means adopted consists in providing supplementary air valves capable of

being opened more or less as required. Such a valve is of use owing to the variable quality of the air, which may contain a very variable proportion of moisture, depending upon the weather conditions and the locality.

IGNITION.—Electric ignition has entirely superseded the earlier methods of firing the mixture in actual contact with an incandescent tube or wire, and at the present time the system universally adopted consists in passing a spark through the compressed mixture in the cylinder, but the means adopted for producing the spark and for applying it are not always the same. In general the essential elements of an ignition system are the current generator and the ignition plugs, which are inserted one in each cylinder. In addition there is provided, in the case of a multiple cylinder, a commutator for controlling the order or timing of the explosions in the several cylinders.

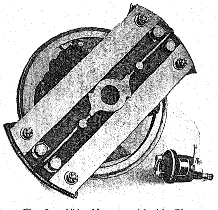


Fig. 583.—Albion Magneto and Ignition Plug

In the low-tension system, which was the first to be extensively used, the ignition plug consists of a contact capable of being opened and closed

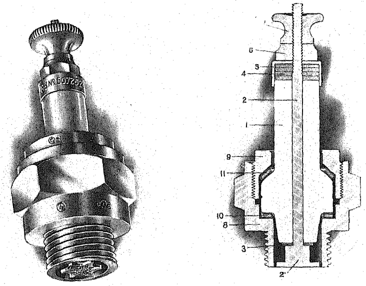


Fig. 584.—High-tension Sparking Plug

by mechanical means. When the contact points are almost touching one another, only a comparatively small pressure is required to produce a spark between them, and as the points are drawn apart the torrent of sparks continues for a time. A contact plug of this description, as used

upon the Albion car, is indicated in fig. 583. Sparking plugs of the kind illustrated in fig. 584 necessitate the use of a high electrical pressure in order to produce an arc between the disc, 2, and the body of the plug, 8, which are separated by an air gap of considerable resistance. For the production of the spark either batteries in conjunction with an induction coil for increasing the electrical pressure, or a small magneto-electric machine driven by the engine, may be used, but in many cases both arrangements are provided—the induction coil being used when starting and upon emergencies. A single primary battery gives a pressure of about $1\frac{1}{4}$ volt and a secondary cell 2.2 volts, and as many of these cells coupled in series would be required to give the necessary pressure at the ignition plug, an induction coil is used to raise the pressure. The Ruhmkorff or

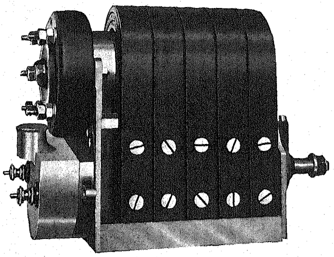


Fig. 585.—Speedwell High-tension Magneto

induction coil consists of two independent coils wound upon a soft-iron core, and of a condenser composed of two sets of thin, tinfoil metal sheets, arranged alternately in a pile and insulated from one another by thin layers of waxed or varnished paper. When current from one or more cells is allowed to momentarily flow in the small coil, which consists of a few coarse turns of wire, an entirely independent flow of current is induced in the secondary coil, composed of many fine turns; and although the energy is of the same amount in both coils, the voltage of the secondary induced current is greater than that of the primary in the ratio of the number of turns in the two windings, while the quantity of the current is less in the same proportion. It is only at the moment when the flow commences or ceases in the primary winding that any induced flow takes place in the secondary; and in order to obtain a more continuous action it is necessary to provide an automatic contact maker, which will rapidly make and break the primary circuit. Each make and each break of the primary circuit induces the same high-tension current in the secondary coil, but the two induced currents flow in opposite directions,

and as neither is sufficiently intense to jump the air gap at the sparking plug, the condenser already mentioned is connected across the circuit for the purpose of intensifying the flow at the break. As the suddenness with which the current rises or falls really determines the induced pressure, the current at the make, when retarded by the action of the condenser, is a comparatively feeble one, while the current at the break, which is assisted by the action of the condenser, is sufficiently intense to jump the gap at the ignition plug and produce a torrent of sparks.

Batteries and accumulators require renewing and recharging, and in this respect they are not so convenient as the MAGNETO, which is very commonly used for ignition purposes. Essentially the magneto consists of a coil of wire which is mechanically moved through the magnetic field

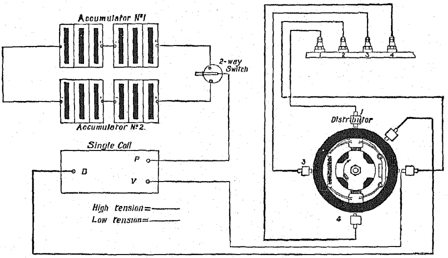


Fig. 586.—Daimler Accumulator Ignition, showing arrangement of distributor

between the poles of a magnet. As the coil cuts through the lines of magnetic force there is induced in it a current, the voltage of which depends at any instant upon the rate at which the lines are being cut; and since in practice the coil is generally moved in a circle, so as alternately to pass before the north and south poles of the magnet, the current pressure alternately rises from zero to its maximum positive value, and then falls through zero to a corresponding negative maximum. By the addition of a secondary winding to the magneto armature a high-tension alternating current may be obtained as a result of the influence of the primary alternating current. In fig. 583 is illustrated the Albion type of low-tension magneto and contact-lever ignition plug, and the Speedwell high-tension magneto is illustrated in fig. 585. One typical ignition system is illustrated diagrammatically in fig. 586, which shows the arrangement adopted in the case of a Daimler four-cylinder engine. There are two sets of six accumulators provided, and a two-way switch which permits of one or other being used as required. One terminal of each battery

is earthed, and the other is connected through the switch to the induction coil, which in this example serves for all four cylinders. The secondary currents are distributed by the commutator to the ignition plugs in the required order, as determined by the arrangement of the cranks.

SPEED AND TRANSMISSION GEAR.—Alterations of the speed cannot be effected in the case of the internal-combustion engine as in the steam

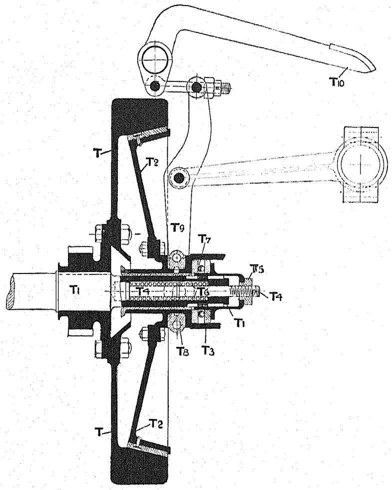


Fig. 587.—Albion Friction Clutch

T, Flywheel. T_1, end of crank shaft. T_2, Inner clutch member. T_3, Sleeve carrying T_2. T_4, Clutch bolt. T_5, Adjustment nut on T_4. T_6, Clutch spring. T_7, Ball-thrust bearing. T_8, Clutch collar. T_9, Clutch fork. T_{10}, Clutch pedal.

engine, where the supply of steam at each stroke may be varied as desired, and it is therefore necessary in the former case to introduce gearing for reducing the speed and at the same time increasing the driving force applied at the wheels of the car. It will be evident that since the power developed by the engine remains unaltered, an increase of the driving force can only be obtained by a corresponding reduction of the speed.

Referring to figs. 575 and 577, it will be seen that the gear box is in both examples placed immediately behind the engine, from which it is driven through a friction clutch. This friction clutch permits of the engine being disconnected from the transmission system when it is desired to stop the car without stopping the engine itself. A clutch of the internal-cone type, in which the leather face of one portion is pressed tightly into contact with the metal face of the other, is illustrated in section in fig. 587, and for comparison a section of a typical friction disc clutch is given in fig. 588. In the latter case the power is transmitted by friction through a number of metal discs connected alternately to the engine and the transmission shafts. When the discs are pressed together, by operating the clutch lever and advancing the pressure plate G, the sets of friction discs P and N grip and transmit the drive from the engine to the gear-box shaft.

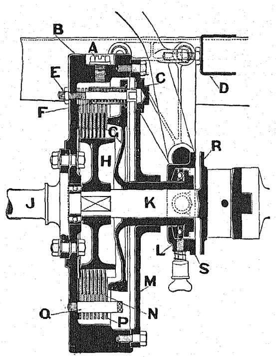


Fig. 588.—Argyll Friction Clutch

A, Oil inlet. B, Flywheel. C, Clutch pressure springs. D, Chassis cross frame. E, Spring adjusting nut. F, Spring box. G, Pressure plate. H, Transmission-shaft wheel. J, Engine crank shaft. K, Transmission Shaft. L, Clutch collar ball race. M, Cover. N, Driven plates keyed to H. P, Driving plates. Q, Disc guide pins. R and S, Friction-stopping discs.

Gear boxes of endless variety have been devised by the various makers of cars, but, as the conditions to be satisfied are in the majority of cases the same, the essential features differ only in arrangement and details. At the present time there is no positive mechanical gear capable of giving any desired speed reduction from that of the engine to zero, and in the gear boxes in common use the changes of speed are made in definite stages. For cars of small powers two forward speeds and one reverse speed may be provided, but for higher-powered cars four forward speeds and one reverse are frequently considered necessary. In the particular example of the Argyll type of gear box, shown in fig. 589 with the cover removed, there are provided three forward speeds and one reverse. In this arrangement the driving shaft P is not continuous with the propeller shaft, although it appears to be so, and the motion can only be transmitted directly from one to the other through the clutch D and E, the former portion of which can be moved along the squared end of the propeller shaft. When the wheel Q is moved towards the right to its full extent

the clutch D becomes disengaged from the driving-shaft clutch, and the clutch L engages with the clutch N attached to the face of the wheel O, which runs idly upon the shaft but in constant mesh with the countershaft wheel R. To obtain the second speed the wheel Q is therefore moved to the extreme right, and the motion is transmitted indirectly through the wheels on the countershaft.

For the first or slowest speed the wheel Q must be placed in its mid

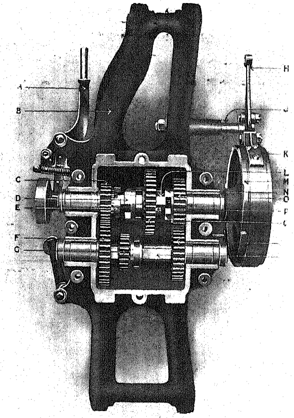


Fig. 589.—Argyll Three-speed Gear Box, showing cover removed

position with both clutches clear of those on the driving and propeller shafts, and the countershaft pinion G must then be slipped along the squared portion of the shaft until it comes into mesh with the wheel Q, to which the motion is as before communicated but through a different gear ratio. The reverse speed is obtained by disengaging the wheels G and Q, and then connecting them through an intermediate wheel U carried upon the lid of the gear case, as shown in the illustration fig. 590. Any arrangement which necessitates the bringing of one moving spur wheel into mesh with another is objectionable, but the directness and simplicity of the

system has made its adoption very general. There are, however, gear boxes in use in which the wheels remain always in mesh, and the required changes of gear are obtained by coupling one or other of the wheels to its shaft through internal friction clutches. In the well-known Dion Bouton design such clutches are used, but there are others in which the various gears are coupled by means of external clutches.

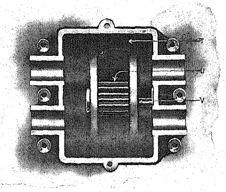


Fig. 590.—Gear-box Cover with Reverse-motion Pinion

DIFFERENTIAL GEAR.—Whatever method of driving the wheels is adopted, it is necessary to drive them separately through a balance or differential gear, as otherwise the wear of the tyres would be considerable, owing to the slipping of one or other of the wheels when running round a curve. When the steering wheels are so directed as to make the car round such a curve, the outer driving wheel must necessarily travel over a longer arc than the inner wheel, as the radii of the paths traversed by them differ considerably. To prevent slipping, therefore, the wheels must be driven in such a way that they are capable of some relative rotation. To make the action of the differential gear clear, its elements, as represented in fig. 591, may be compared with the well-known arrangement of horse trace bars (fig. 592), to which the gear is closely analogous. At any instant the actual motion of the vehicle is the mean of the motions of the horses attached to the trace bars at A and B. In fig. 591 the bevel wheels D_1 and D_2 directly drive the road wheels E_1 and E_2 respectively, and they gear with one another through the satellite bevel C carried idly by the wheel A, to which the driving power is transmitted from the propeller shaft. When the steering wheels are so held that the car is compelled to run in a straight path, the whole of the differential rotates as one piece with the driving wheels, and the satellite wheel C does not rotate upon its spindle. If, however, the steering wheels cause the car to move at the same speed round a curve, one of the driving wheels will move somewhat faster and the other correspondingly slower, and the relative motions of the wheels will be compensated by a rotation of the satellite wheel upon its spindle.

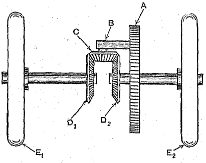


Fig. 591.—Elements of the Differential Gear

In the case of a chain-driven chassis, the differential gear is placed between the two portions of the chain sprocket-wheel axle, from which

the rear wheels are driven, as shown in figs. 575 and 576; but in the Cardan-shaft arrangement (figs. 577 and 578) the rear axle itself is divided to take the differential gear. This latter arrangement necessitates the use over the axle of strong outer sleeves to carry the weight, which the divided shaft alone would be too weak to bear. A section through the bevel gear-driven live axle of an Argyll car is given in fig. 593, which shows at CC the sleeve arrangement. E_1 is the main shaft, which transmits the motion of the engine through the universal coupling at C_1 to the differential gear wheel corresponding with the wheel A of the explanatory diagram, fig. 591.

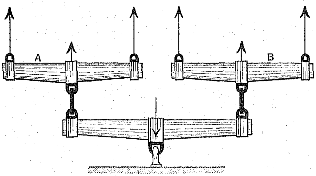


Fig. 592.—Trace Bars analogous to the Differential Gear

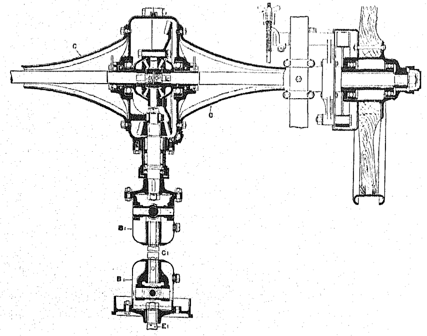


Fig. 593.—Sectional Plan of the Argyll Live Axle

There are two satellite pinions which run on spindles attached to the wheel, but one only is essential. Although bevel wheels are very frequently used for the differential gear, spur wheels in the form of an

epicyclic train are also sometimes employed, and this latter arrangement can be made a very compact one. Fig. 593 also shows the arrangement of a hub of one of the road wheels in section, and the arrangement of the brake drum attached to it.

STEAM MOTOR CARS

Steam cars are at the present time manufactured by a comparatively limited number of makers, and the same widespread attention has not therefore been concentrated upon their development. Those who have

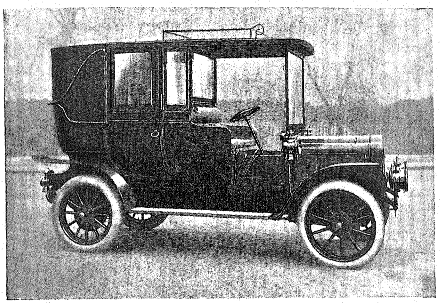


Fig. 594.—General View of the White Steam Car

specialized in the design and manufacture of steam cars have, however, brought them to a condition of very considerable perfection, and many of the difficulties of the system have already been successfully overcome. A steam car in outward appearance does not necessarily differ from a petrol-driven one, and the differences are in some cases difficult to recognize. This is particularly so in the case of the steam car (fig. 594) manufactured by the White Company. As in the petrol car, the steam engine is placed in front under a hood, and for the radiator is substituted a very similar type of condenser, in which the exhaust steam from the engine is cooled before being returned to the boiler. A plan of a White chassis, showing the arrangement of the essential elements, is given in fig. 595, and the under side in fig. 596. The steam generator L is situated near the middle of the frame, and below it is placed the main burner. At the front end is placed the engine F, to which the steam is conducted from the generator through the pipe G. As already stated, the condenser A is situated at the front, and immediately behind it is the fan B, which pro-

motes a circulation of cold air over it. In a steam car the transmission gear is of the simplest description, as there is no necessity for any change-speed gear box or clutch, although one gear is sometimes fitted to avoid the necessity of overloading the engine with live steam when climbing hills. From the under view of the White car (fig. 596) it will be seen

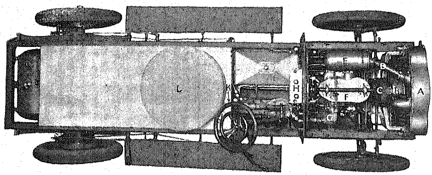


Fig. 595.—White Steam Car Chassis (plan)

that the Cardan shaft runs directly through from the engine to the differential gear on the back axle, the rear universal joint being indicated at P.

Whilst the internal-combustion engine necessitates the use of gear boxes, clutches, elaborate lubrication arrangements, and ignition devices, the steam car, on the other hand, involves, in addition to the engine generator and burner, the provision of means for automatically regulating

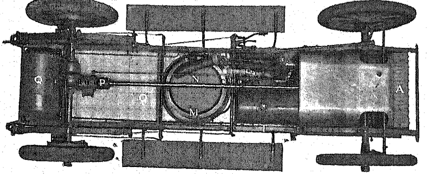


Fig. 596.—White Steam Car (under view of chassis)

the heat of the burner flame and the supply of water to the boiler. These automatic arrangements are shown diagrammatically in fig. 597, which shows both the oil-fuel and the feed-water systems. Oil fuel for the main burner E_1 is stored in the tank B, from which it passes to the burner admission valve B_2. When the boiler is cold, and there is no steam for the automatic supply, oil is admitted to the burner by means of the bypass valve B_3; but this valve is closed as soon as sufficient steam is raised in the boiler. Under normal working conditions the engine-driven feed pump A_1 draws

water from the tank A and forces it through the feed-heater coils A_3 to the flow regulator A_4, which opens a return bypass A_7 back to the tank A whenever the supply from the pump exceeds a predetermined limit. At the same time a needle attached to the plunger of the regulator A_4 controls the flow of oil through the valve B_2 in accordance with the flow

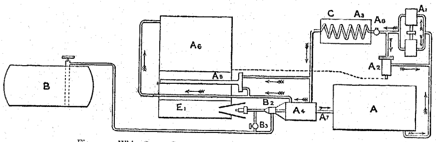


Fig. 597.—White Steam Car. Diagram of Oil-fuel and Feed-water System

of water through A_4. In this way the oil consumed in the burner is varied to suit the demands for steam. To prevent any possible excessive rise of temperature a thermostat A_5 is provided above the burner E_1. When the temperature rises unduly, the thermostat opens an auxiliary passage from the feed heater to the boiler A_6 until the additional flow of feed water

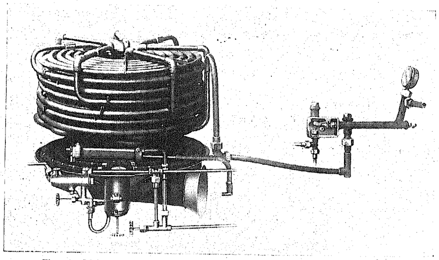
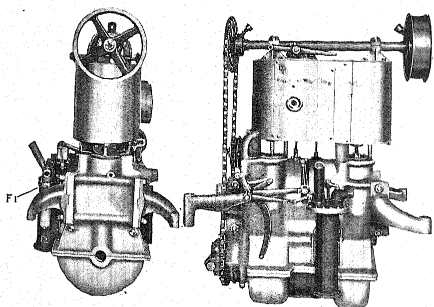


Fig. 598.—White Steam Car. General View of the Generator, Burner, and Automatic Valves

reduces the temperature to the fixed limit. It will be seen that the arrangements are somewhat complicated, but, on the other hand, the action is automatic and regular, and the work of the driver is simplified.

An external view of the generator, the burner, and the automatic arrangements described above is given in fig. 598. The generator itself consists of a long tube coiled, as shown in the illustration, with the burner

underneath. The action of the generator is as follows. Water is pumped into the upper coils, and as it is forced downwards through the succeeding layers it becomes heated, until at a certain point it flashes into steam. Below that point the coils contain steam alone, which becomes superheated before it passes to the engine. The several coils are joined in series, but the connections are such that the water or steam from one coil must pass upwards beyond the level of the top layer before it can descend to the next coil. Flash boilers of this description contain at any moment a very



End View Side Elevation

Fig. 599.—The White Steam Car Engine

small quantity of water or steam, and a rupture of any part can have no disastrous results.

Single-acting engines, resembling in some respects the internal-combustion type, are favoured by several makers of steam cars, but in the White car the engine is a vertical compound one. An external view of the 30-h.p. type of engine is given in fig. 599, which shows the end view and also the left side of the engine with the feed-water heater, feed pump, and regulator attached to the casing.

ELECTRIC MOTOR CARS

Electric cars are of all types the simplest from the constructional point of view, and they possess advantages which, under certain conditions, more than balance their disadvantages. Under average conditions the accumulator-driven car cannot compete with the petrol-engine car, its usefulness being limited by the great weight of the lead-plate storage cells, and by the

necessity for recharging after from 30 to 40 miles over ordinary roads in fair condition. Until some radical improvement of the durability, weight, and capacity of the accumulator has been effected, it is improbable that the use of electric cars will increase to any considerable extent except under conditions such as prevail in large towns where the road surfaces are well finished and where smooth and quiet running is desired in preference to economy of working. Storage batteries have already been described, and it is therefore unnecessary to describe them in detail here. Each cell most frequently consists of several pairs of lead plates immersed in acidulated water, and when fully charged such a cell is capable of supplying a current at a pressure of about 2.2 volts. As the charge becomes exhausted the pressure falls gradually to 1.9 volt, and after this point the fall increases rapidly. A very rapid discharge or a sudden fall, such as takes place when the voltage falls below 1.9, results in unequal action over the plates and in unequal expansion, which causes them to buckle and displace the paste from the interstices of the plates. It is largely this feature that renders the accumulator unreliable for ordinary motor-car work, as the heavy discharges that may be required when climbing a hill tend to buckle the plates and destroy them. As each cell gives an average of about 2 volts, and as the voltage at which the electric motor for an electric car is designed to run at is usually about 100 volts, it is necessary to provide fifty cells, which must be connected in series. A battery of this kind represents in general one-third of the total weight of the car. If the working voltage were less than 100 the number of cells required would be less, but as the current for the same power would be proportionately greater the size of the plates would necessarily also be greater, and the weight of the battery would not be considerably altered. In the case of the motor, however, the weight would be greatly increased, as the size is determined largely by the current to be carried by the armature. In practice a pressure of about 100 volts is most frequently adopted.

For short periods the motor can be made to develop nearly double its normal power, but this heavy load cannot be carried for longer periods without danger of overheating or burning the armature. To prevent the possibility of overloading the motor by applying the mechanical brakes before the current is cut off, a special switch is provided in connection with the foot pedal which applies the brake. When the pedal is slightly depressed the current is cut off and the car runs freely, until by further depressing the pedal the brake is brought into action. When the pedal is released again the reverse action takes place; that is, the brake is released before the current is switched on to the motor. For vehicles of greater power it has been proposed to substitute for the accumulators an engine and a dynamo to supply the current for the motor. With this arrangement all the advantages of the electric system are retained, while the chief objections inherent to accumulators are avoided, but at the present time this petrol-electric system has not been very generally applied.

CHAPTER XII

NAVIGATION

DEVELOPMENT OF MODERN STEAMSHIPS.—Until the middle of the nineteenth century all ocean traffic was carried by sailing ships, although for fifty years previously the problem of economically propelling large ships by means of steam engines had been receiving the attention of many engineers and builders. Sailing ships had during that time been gradually brought to a state of great perfection, and the performances of some of the famous sailing clippers were remarkable. One of these wooden sailing vessels, called the *Sovereign of the Seas*, a vessel of over 2400 tons, maintained on one occasion an average speed of 18 knots for 24 hours, and in the frequent races that took place across the Atlantic speeds of 17 knots maintained for long periods were not uncommon. Towards the middle of the nineteenth century the increased scarcity and cost of English oak, which was greatly superior to any of the imported oaks or other foreign timbers, led to the introduction of iron, which could be produced in Britain at a cost sufficiently low to permit of competition with shipbuilders in America, where timber was plentiful. About the same time, by the introduction of the system of compound expansion, the consumption of steam in marine engines was appreciably reduced, and it then became possible for the steam-driven vessels to compete with the sailing ships, which until then had monopolized the ocean traffic. At the present day sailing ships are still best suited for certain kinds of traffic, where speed is not of serious importance, but these vessels are built of iron as in the case of the steam-driven ships. To the introduction of iron for the construction of the hulls, and to the development of the multiple-expansion steam engine, is due the vast increase of traffic between the countries of the world that has taken place within the last fifty years.

EARLY STEAMBOATS.—It is generally accepted that the first practical application of the steam engine to marine propulsion was made by MILLER and SYMINGTON, who in 1788 carried out successful trials with a steam vessel, which attained a speed of 5 miles an hour on Dalswinton Loch, in Scotland, and in the following year with a second vessel on the Forth and Clyde Canal. In 1802 Symington constructed for Lord Dundas the *Charlotte Dundas*, which was propelled by means of a stern paddle wheel driven by what was the first horizontal, direct-acting engine ever constructed. HENRY BELL and FULTON, whose names are closely linked with the development of the steamboat, were present at the trial trip of the *Charlotte Dundas*, and the experience thus gained was applied in the design of the successful vessels which these engineers afterwards constructed. Fulton returned to his own country, America, and there in 1807 built the *Clermont*, to which was fitted a set of 20-h.p. engines constructed by Boulton & Watt, of Birmingham. This vessel was run for some time between New York and Albany, and was the first of a long series of successful attempts. Henry Bell, of Glasgow, in 1811 determined to

apply his extensive knowledge to the construction of a steamboat, and in 1812 his boat, the *Comet*, made its first voyage. This vessel, the name of which was suggested by the appearance of the great comet of 1811, plied regularly between Glasgow and Greenock, and for many years its performances remained unsurpassed. From this time onwards the progress of steam navigation was rapid, and many improvements in the boilers and engines were introduced, but until 1819 no serious attempt to cross the ocean in a steamship had been made. The auxiliary steamship *Savannah*, which first crossed the Atlantic from Charlestown to Liverpool, was a full-rigged ship, to which engines and paddle wheels were added. When the wind was favourable the paddle wheels were disconnected and hoisted on deck, as the coal capacity of the bunkers was too limited to permit of the engines being run for a long period.

THE GREAT WESTERN.—At the British Association meeting of 1837, at Liverpool, the subject of ocean steamers was considered, and it was shown by calculation that steam communication with America could not be conducted at a profit, as the quantity of coal required for a voyage under continuous steam would not leave sufficient room for the carriage of cargo. These conclusions were within a year disproved by the voyages of four ships across the Atlantic under continuous steam, and one of these steamships, the *Great Western*, earned for its owners a dividend of 9 per cent. The hull of the vessel was of timber trussed with iron, and the gross weight was 1320 tons. Her engines, built by Maudslay, Sons, & Field, developed 750 h.p., the cylinder diameter being 73.5 in. and the stroke 7 ft. The average speed was from 8 to 9 knots, and the average voyage occupied about fifteen days, during which time about 600 tons of coal were burned. Although the wooden hull of the *Great Western*, which had an extreme length of 236 ft., showed no signs of weakness after many stormy passages, it was evident to the designers of ships that it would be impracticable to employ timber for the structure of ships of over 300 ft. length. The hull of a vessel at sea is subjected to stresses of a very variable and complicated kind. It may at one moment be water-borne near the ends upon two waves, in which case the structure may be compared with a uniformly loaded girder supported at the ends, and immediately afterwards it may be supported near the middle. Under such conditions the upper and lower portions of the hull are subjected to stresses which change frequently from tension to compression. Forces of a still more complicated nature are called into play as the ship rolls and pitches, and it is necessary to make ample provision for both transverse and longitudinal stiffness.

THE GREAT BRITAIN AND GREAT EASTERN.—With the advent of the *Great Britain*, built at Bristol in 1843 from the designs of Mr. BRUNEL, the use of iron for shipbuilding became firmly established, and all large vessels thereafter were so constructed. The *Great Britain* is notable, not only on account of its size and of the use of iron throughout, but also as regards the method of propulsion, a propeller being used instead of paddle wheels. In the year 1856 the introduction of the system of compound expansion gave further impetus to the already rapid progress of steam navigation, as the consumption of coal was reduced to almost one-half of

what it had been in the best designed and most economical marine engines, and the cargo-carrying capacity was proportionately increased. Provided full cargoes are always obtainable, a single large ship is more economical

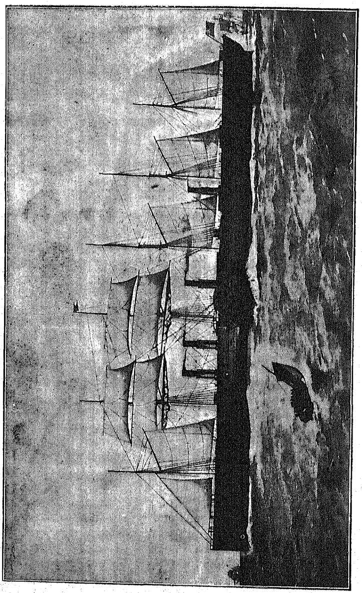


Fig. 600.—The Great Eastern Steam and Sailing Ship

than a number of smaller ships which together have the same cargo capacity; and the tendency has therefore been with the growth of traffic to increase the sizes of cargo ships. In the case of the *Great Eastern*, which, so far as size and loaded displacement are concerned, was only surpassed in 1905 by the White Star liner *Baltic*, the main intention of the promoter,

Mr. I. K. Brunel, was to build a vessel which would be able to complete the voyage to Australia without having to coal at an intermediate station. With Mr. Brunel was associated MR. SCOTT RUSSELL, who was responsible for the main features of the hull design; but to Brunel is due the credit of having proposed the cellular construction adopted for the bottom and upper deck. Scott Russell, on the other hand, introduced the system of longitudinal and transverse bulkheads, which provide the necessary stiffness and also divide the hull into separate water-tight sections. The length of the ship between perpendiculars was 680 ft., the breadth 83, and the depth from upper deck to keel 58 ft. Her gross tonnage was nearly 19,000, and the loaded displacement 32,000 tons. Both systems of paddle and screw propulsion were adopted, and in addition she was provided with sails, as shown in the illustration, fig. 600. For driving the paddles a two-cylinder oscillating engine of 5000 i.h.p. was used, and for driving the propeller a trunk engine of 6600 i.h.p. was installed in a separate engine room. Steam at a pressure of from 25 to 30 lb. per square inch was supplied to the engines by boilers of the Box tubular type, and the sea speed attained was from 13 to 14 knots, with a daily coal consumption of 350 tons.

STEEL SHIPS.—As in the case of the substitution of iron for wood, a further reduction of about 15 per cent of the weight was effected by the introduction of mild steel, which is now universally employed, but its introduction was not accomplished without several failures, due chiefly to defects of composition and manipulation, which have now been entirely overcome. With the further development of the steel industry it is probable that still stronger and more ductile materials may become available for the building of ships, and already high-tensile steels are being used in conjunction with mild steel for the hulls of torpedo craft, where strength and lightness are essential features.

TRIPLE-EXPANSION ENGINES.—A further stage in the progress of steam navigation was reached in the year 1874, when it was practically demonstrated that the use of triple-expansion engines meant a still further reduction of the coal consumption and an increase of the cargo capacity of the vessel. Quadruple-expansion engines have also been fitted to a number of ships, but it is doubtful if any marked advantage is to be gained by dividing the expansion over a greater number of stages, and at present the high steam pressures and temperatures that would warrant a further increase of the stages of expansion cannot in practice be readily obtained or employed.

TURBINE STEAMERS.—With the introduction of the steam turbine the whole aspect of ship propulsion has undergone a remarkable change, and already the reciprocating engine has been extensively superseded by it for certain classes of vessels. In the reciprocating engine the extent to which the steam can be expanded is limited by the permissible size of the low-pressure cylinders, whereas in the turbine the flow of the steam is continuous, and the expansion can be carried to a much greater extent. There are, however, certain disadvantages which so far have prevented the general adoption of the turbine.

As has already been explained in a previous section, to obtain the

maximum economy the rotor vanes of a turbine must move at a linear speed determined by the steam pressure across each stage of the turbine. By increasing the number of stages, as in the Parsons mixed system, the speed of rotation can be reduced, but for mechanical reasons it is not possible to increase the overall length of the turbine beyond certain limits. If the speed be reduced by increasing the diameter of the rotor the weight of the plant becomes excessive, and at the present time no great saving of weight is effected by the use of turbines, especially when account is taken of the greater bulk of the condensing plant involved. It is in the difficulty of finding a propeller that will efficiently transmit a large power at a high speed that is the chief objection to the use of marine turbines. It will be evident that in the design of a marine turbine installation a compromise must be made between the turbine and the propeller to obtain the best combined efficiency. In the case of one large modern battleship the total power of 24,000 h.p. is divided over four sets of turbines and four propellers, each of which has to transmit about 6000 h.p., and the speed adopted is 350 revolutions per minute. In the case, however, of a smaller vessel, in which each of the three propellers has to transmit about 1000 h.p., a speed of 600 is possible, and the weight of the turbines is proportionately very much less. Various mechanical and hydraulic transmission devices designed to transmit the power of the turbines to the propellers at a reduced speed are at present being experimented with, and already good results have been obtained in the *Vespasian*, a vessel of 4350 tons displacement fitted with spur reducing gearing.

Another disadvantage of the marine steam-turbine system lies in the necessity for separate reverse turbines, as the direction of rotation of the turbine rotor cannot be changed at will. These reverse turbines are usually contained in the same casings as the low-pressure turbines, and while the latter are rotating the shaft in the ahead direction, the blades of the low-pressure turbine rotate idly in the vacuum of the condenser with but slight friction losses.

By a combination of the reciprocating engine and the steam turbine the advantages of both systems may to a large extent be retained, and this arrangement has recently been adopted in several large ships. The exhaust steam from the main reciprocating engines and from the auxiliary engines is further expanded in the exhaust-steam turbine, the vacuum for which is maintained by a specially designed condensing plant, and it is possible that the future of the turbine lies in this direction.

To overcome all propeller difficulties, and at the same time to dispense with the reverse turbines, it has been proposed to drive the propellers at a moderate speed by means of motors supplied with current from turbo-generator sets. Such an arrangement would appear to have many advantages under the present conditions, but as further experience is gained in the design of mechanical reducing gears and other devices, the necessity for the arrangement proposed will doubtless become less.

MARINE BOILERS.—For the generation of the steam supply, cylindrical Scotch boilers are still almost universally employed in merchant vessels, but for large passenger steamers and warships other types have been very gene-

rally adopted either in place of the Scotch boiler or in addition to it. A cylindrical boiler of the Scotch type has the great advantage of simplicity and, when well attended to, of durability. It cannot, however, be made to increase rapidly its output when a sudden demand is made for more steam. Water-tube boilers have the advantage of greater flexibility as regards rapidity of steaming, and to some extent they do not constitute so grave a danger in the event of an explosion, as the quantity of water contained by them at any moment is comparatively small. For warship purposes, where compactness is of first importance, and where the available headroom under the protective deck is small, water-tube boilers are particularly suitable and are very generally installed. The smallness of the parts and the ease with which they may be removed or repaired are also important features which do not belong to the cylindrical boiler. Recent proposals have been made to substitute gas producers for the boilers, and internal-combustion engines for the steam engines or turbines, hitherto used, and at the same time to dispense with the auxiliary plant necessary for the working of the steam installation. Experiments upon a small scale only have been carried out, but the chief objections appear to lie in the difficulty of starting and reversing, and to troubles arising from unclean gas. Large gas engines cannot yet be depended upon to run continuously for long periods, and a similar objection exists in the case of producer plants.

TYPES OF VESSELS.—Numerous types of vessels have been gradually evolved to meet the requirements of particular kinds of traffic, and there are now generally recognized forms which have been found to be best suited to certain routes. In general the arrangement of a large cargo steamer is such that the capacity of the forward hold is about equal to that of the after hold, which is separated from the former by the engine-room and boiler spaces. This arrangement permits of a better distribution of the cargo, and does not necessitate the extensive use of ballast tanks for trimming purposes when carrying a full cargo of homogeneous materials such as grain, but there are other arrangements in which the engines and boilers are placed farther aft, thus reducing the length of the propeller shafting and the tunnel spaces, while the forward and middle portions of the hull are left more free for cargo purposes. In vessels which may be required to carry homogeneous cargoes of grain or coal, the holds are not subdivided by decks, which would prevent access for trimming purposes in the event of the cargo shifting.

WELL-DECKER SHIPS derive their name from the open space or well provided between the forecastle and the bridge house. These ships possess excellent seagoing qualities and are not readily swept by waves entering over the bows. In such a case the water is caught by the well, from which it passes away through the large scuppers provided. A novel single-deck construction, known as the TURRET TYPE, which has come into extensive use for the carriage of homogeneous cargoes, is illustrated in fig. 601, from which it will be seen that the sides are bent inwards at a level above the water line, and are then carried upwards again to form the so-called turret, which serves as the navigating and cargo-working

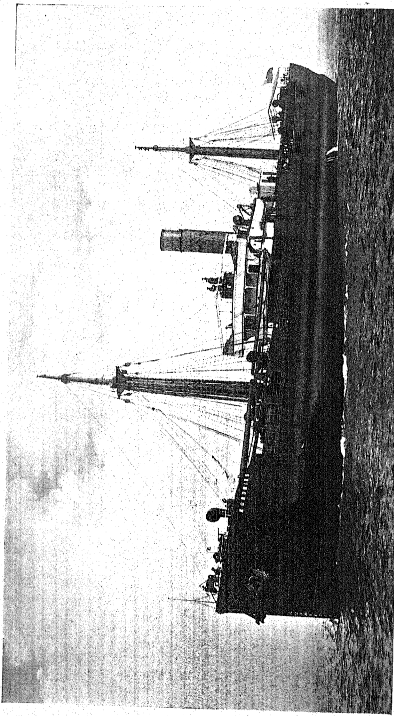


Fig. 601.—Typical Turret Ship

deck. The engines are situated at the after end, an arrangement which ensures the propellers being sufficiently immersed when the holds are empty, and which leaves the deck clear for the working of the cargo. A somewhat similar construction, which provides a large additional water-ballast capacity, is shown in section in fig. 602. In this arrangement the sides of the ship are carried up as shown to form wing ballast tanks, which are used when the vessel is sailing in ballast, as is frequently necessary in the British import trade with America.

A special type of vessel has also come into extensive use for the

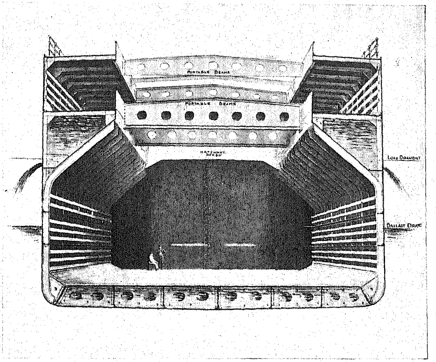


Fig. 602.—Section of Vessel showing Wing Ballast Tanks

carriage of petroleum in bulk, in which case the oil is pumped directly into or from the holds when loading or discharging. As the bulk of the oil varies considerably with changes of temperature, it is necessary to make provision for expansion, and this is generally done by carrying trunks upwards from the deck. If, then, the bulk increases, the oil is free to rise in the trunk, and all danger of a serious increase of pressure in the holds is avoided. To prevent violent surging of the oil, when the tanks are only partially filled and when the ship rolls, the holds are divided by longitudinal bulkheads, as well as by numerous transverse bulkheads. When the engines and boilers are placed amidships, double bulkheads are arranged aft and abaft of them, and the spaces between are either filled with water or kept free of oil by special pumps. By

placing the machinery right aft, only one set of bulkheads is required, and this arrangement is one that is frequently adopted. In addition to the pumps required for handling the cargo, it is necessary to install ventilating fans for sweeping out the highly explosive mixture of air and oil vapour which accumulates in the bottom of the tanks after the discharge of the oil.

For the frozen-meat trade the cargo spaces of the special steamers employed are subdivided into compartments which are lagged with non-conducting materials to prevent the entrance of heat, and a low tempera-

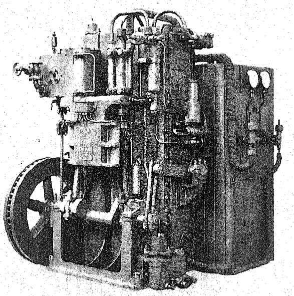


Fig. 603.—The Hall Refrigerating Machine. Carbonic Acid System

ture is maintained by means of refrigerating machines, of which there are several types. In one of the most generally used systems (fig. 603) the low temperature is obtained by the expansion of liquid carbonic acid, which, in the act of expanding against a resistance, absorbs heat from the surrounding bodies. Cooled brine is circulated in pipes through the various cargo chambers, where it absorbs the heat of the air, and then through the refrigerator, where its heat is abstracted by the expanding gas.

PASSENGER STEAMERS.—The development of the modern passenger steamer has been largely determined by the public desire for speed, safety, and comfort. This preference of the public has resulted in a strong rivalry between the shipping companies of Britain and other countries, and, as a result, the sizes and the speeds of mail passenger steamers have steadily

increased. A considerable increase of speed is only obtainable by a very considerable expenditure of coal, and the cost of running certain express passenger liners has already exceeded their unaided earning powers. In the case of the *Kaiser Wilhelm II*, of the North German line, and of the *Lusitania* and *Mauretania*, of the Cunard Company, the expense of running these vessels is, to some extent, met by Government subsidies, as it is of importance to the Governments concerned that very fast vessels should be available for transport and scouting duties in the event of war.

To the desire for comfort may, to some extent, be attributed the large increase in the sizes of ships that has taken place in the transatlantic passenger trade. As the size of the ship is increased the effects of the waves become less, and in the largest vessels there is little discomfort from the rocking and pitching of the ship under even the worst weather conditions. Excessive rolling of ships is partly prevented by the use of bilge keels projecting from the sides of the vessel; but other devices have been employed to reduce still further the disagreeable rolling which causes so much discomfort to many passengers. In one arrangement, which was first adopted in H.M.S. *Inflexible*, and later in the *City of Paris*, the period of rolling was damped by the motion of a large body of water enclosed in a specially formed tank. As the ship heeled over, the water tended to flow from one portion of the tank towards the other, but, by retarding the flow, the motion of the water was made to oppose that of the ship. Trials have recently been carried out with other arrangements, in which the damping of the rolling motion is effected by means of heavy rotating flywheels, or of large heavy masses of metal constrained to move in definite paths; but the masses required are considerable, and only the water-tank system has so far survived the experimental stage.

SAFETY.—In the early days of ocean travelling the risks incurred by the passengers were very great, and vessels were frequently lost through perhaps some minor accident to the hull, which in ships of modern design would have had no serious results. Accidents still occur, and no vessel, however well equipped or designed, can be considered safe from disaster. Considering, however, the magnitude of the passenger traffic of the present day, and the number of miles traversed, the percentage of losses is remarkably small. Ocean travelling has been rendered comparatively safe as a result of the improvements that have been effected in the construction of ships, in the charting of the seas, in the lighting of the coasts and shoals, and in the installation of wireless-communication apparatus upon the larger passenger vessels.

In the *Great Eastern* an important feature was the double bottom, a system that has been retained in all modern vessels. An accident to the outer skin alone of the vessel, such as might occur through the grounding of the ship or through collision with some submerged object, may not then involve more than the flooding of the space between the outer and inner shells; and there are instances where the safety of the ship has been due entirely to this feature. In the event, however, of the inner shell being pierced, the ship would probably founder if it were not for the arrangement of transverse bulkheads which divide the hull into a number of

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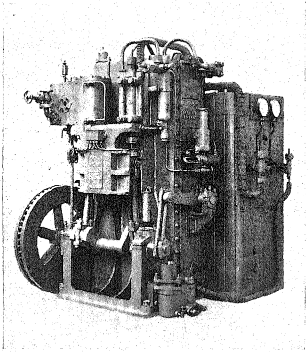

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entirely separate water-tight compartments. With one compartment flooded the ship is designed to be capable of still floating, and in many of the most modern ships two or more of the compartments may be flooded without serious danger of foundering, even in moderately rough weather. In the section (fig. 604) of the old Inman liner the *City of Paris*, built at Glasgow in 1888, the division of the hull by decks and by vertical water-tight bulkheads is clearly indicated; but in this case the bulkheads are pierced by no water-tight doors, and the only way of passing from one compartment to another is over the top of the bulkhead at the level of the upper deck. This arrangement is the only really safe one, but it is very inconvenient; and in later vessels other than the most recent battleships water-tight doors are placed at the various important deck levels. Means are provided for closing these doors rapidly in case of necessity, and in many cases the more important ones below the water line may be operated from one upper position. Automatic arrangements have also been devised for closing the doors when the water rises beyond a certain level in any compartment, but reliance cannot be placed upon any such devices alone. With the adoption of two or more propellers and sets of engines the danger of total disablement when far from land has been largely reduced, since in the event of an accident to one of the engines or the fracture of a propeller shaft it may still be possible to bring the ship into port at a lower speed with the remaining engines. By dividing the total power over two or more sets of propellers and engines the sizes of the parts are also considerably reduced, and in the case of the *Kaiser Wilhelm II* some subdivision of the power is essential for this reason alone. There are in the *Kaiser Wilhelm II* two propellers driven by four sets of quadruple-expansion engines, which develop a total power of 45,000 h.p.

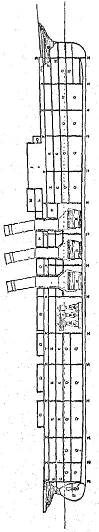


Fig. 604.—Section of the old City of Paris, showing arrangement of Transverse Bulkheads

LUSITANIA AND MAURETANIA.—Until the Cunard turbine-driven liners the *Lusitania* and the *Mauretania* were built, the *Kaiser Wilhelm II*, which was constructed at Stettin for the Norddeutscher Lloyd Company, held the transatlantic record for speed. Her highest mean speed was over $23\frac{1}{2}$ knots, her designed speed being 23 knots. This record has now been broken by each of the later Cunard ships, the *Lusitania* and the *Mauretania*, which were designed for the very considerably higher speed of 25 to 26 knots. These large vessels are each propelled by four screws driven by four sets of turbines, and at the time they were designed there were few data of a comparable nature upon which to base the calculations. To obtain the desired

speed a total power of 68,000 h.p. was provided, and this power is divided equally over the four propellers. Before the vessels were constructed some valuable experience was gained with two turbine-driven vessels, the *Virginian* and the *Victorian*, which were built for the Allan Line Company; and towards the end of the same year (1905) the Cunard Company built two large liners, the *Caronia* and the *Carmania*, which for purposes of comparison were fitted with reciprocating and with turbine engines respectively. As far as possible the vessels were purposely designed to be sister ships, so that a true comparison of the systems of propulsion might be obtained. The *Caronia* was provided with two sets of quadruple-expansion engines capable of developing a total of 22,000 h.p., while in the case of the *Carmania* three sets of turbines of the same total power were installed. Although the results at first obtained from the two former vessels did not satisfy all expectations, the results obtained during the comparative tests of the *Caronia* and the *Carmania* were such as to prove the suitability of the turbine for the propulsion of large high-speed vessels.

CHAPTER XIII

INLAND WATERWAYS

CANAL *v.* RAILWAY.—Inland navigation of the natural waterways and canals of this country has been the subject of much controversy within recent years, and the advisability of improving this system of transport has been recently under the consideration of a special Royal Commission. Upon the Continent and in America the deepening and widening of the waterways has resulted in a large increase of the inland water-borne traffic, and, although the conditions are not in all respects the same, it is held by many that an improvement of the canals and of their equipment would result in considerable economies in this country also. At the present time the Midlands of England are traversed by numerous canals which stretch from the Mersey and the Humber to the Thames, and which connect the larger inland centres with the principal seaports. Many of these canals are, however, of small size, and suitable only for barges of not more than 50 tons capacity; but certain portions, such as those under the control of the River Weaver Navigation Commissioners, have a depth of at least 10 ft., and are capable of accommodating boats of from 300 to 350 tons capacity. Experience has shown that the traffic upon canals can only be successfully conducted in competition with the numerous railroads of this country when the loads that can be carried upon a single bottom are large, as in the case of the River Weaver Canal, where single cargoes of from 200 to 300 tons are common.

CANAL TRACTION.—The power required to haul a boat along a canal is determined chiefly by the amount of the skin friction, and also by the character of the waves that are formed by the vessel as it moves through

the water. From the interesting investigations of Scott Russell, made about the year 1834, it appears that the formation of waves ceases altogether when the speed of the vessel is increased beyond a certain critical point determined by the depth of the water, and that at this high speed the power required to haul a boat upon a canal is greatly reduced. At speeds below the critical point the position of the bow wave is such that the boat lies upon its rear slope, and there is therefore a considerable resistance to the motion. As the speed is increased, the wave length also increases; but when the critical velocity is reached and then passed the waves become short and high, and then practically cease. This remarkable fact, which was first demonstrated by Scott Russell in the experiments referred to above, led to the introduction of the early flyboat

Fig. 605.—Electric Locomotive Towing Canal Barges

passenger services on the Glasgow and Ardrossan and the Forth and Clyde Canals. Each boat was drawn by a pair of horses at a speed of from 10 to 13 miles an hour, and at this speed the power required was much less than at lower speeds. Horse systems of this kind are, however, impracticable for any but the lightest kinds of traffic, and the flyboat services were not long continued. Traction upon the smaller canals is limited to speeds of about 3 to 4 miles an hour, owing to the destructive action upon the banks of the waves formed at higher speeds, and until some reconstruction of the waterways is effected it is doubtful if the traffic upon the canals of this country will become greatly extended. Various systems of haulage have, however, been tried with a view to reducing the cost of transport, and elaborate systems of mechanical haulage have been installed upon certain Continental and American canals. Steam propulsion is very commonly used, but, owing to the erosion of the banks caused by the wash, the speeds are restricted to about 3 miles per hour.

Petroleum and petrol motor boats, which consume a more expensive class of fuel, have also been experimented with, and petroleum-driven boats of from 6 to 40 h.p. are very extensively employed upon the canal

systems of Holland for the transport of heavy cargoes. To any system of separate tractors running upon one bank there is the objection that the tractors must be exchanged whenever the boats require to pass one another, and the first cost of installing the system is considerable. On the Charleroi Canal, in Belgium, and on the Douai section of the Canal d'Aire the tractors run upon the ordinary towing path; but the system has not proved economical, and the wear of the tractors and of the road surface is very great. At Douai, tractors of 10 h.p., weighing about 2 or 3 tons, are used, and the current is supplied by means of overhead wires. Three-

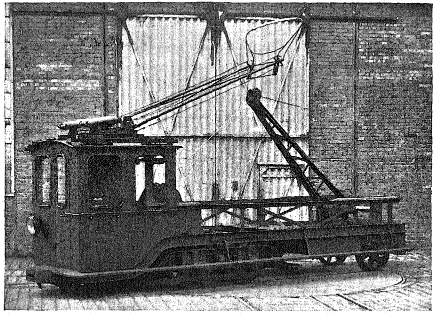


Fig. 606.—Electric Tractor for Canal Barges

phase current collected by three sets of trolleys is used in the case of the Charleroi system, and the cost of installing was particularly heavy.

On the Teltow Canal, in Germany, an electrical towing system of the most complete description was installed in 1905, and in this case the tractors run upon rails on both banks of the canal. Continuous current at a pressure of 550 volts is supplied to the locomotives from overhead conductors, and each locomotive is driven by two 8-h.p. motors, which together are sufficiently powerful to haul two 600-ton barges at a speed of $2\frac{1}{2}$ miles an hour. At higher speeds the wash of the vessels has a serious effect upon the banks, and the waterway becomes quickly silted up. For these reasons, and also on account of the greater power required it has been found necessary to limit the speed to not more than $2\frac{1}{2}$ miles per hour. In the illustration (fig. 605) one of the locomotives is shown towing three barges, and in fig. 606 is clearly indicated the arrangement of the locomotive which was constructed by the Siemens-Schuckert Com-

pany of Berlin. In the United States of America electrical haulage has been experimented with on the Erie Canal, which has suffered to some extent, so far as traffic is concerned, through the increased competition of the railways. In the Erie Canal installation, which has been recently abandoned, electric tractors were employed for towing the barges; but the tracks, instead of being on the road level, as in the other systems mentioned, were carried upon an overhead rail.

LOCKS AND LIFTS.—Owing to the costly cuttings and tunnels that would be required, it is rarely possible in the design of a canal to so arrange the levels that locks are unnecessary; but, so far as the requirements of the traffic permit, the route is so chosen as to involve as small a total rise and as few locks as possible. Each time a vessel is passed through a lock, either upwards or downwards, it is at the expense of a lockful of water, which must be replaced by the inflow of water at a higher level, and the adequate supply of water at the higher levels is often a matter of serious importance. In Belgium and Germany, where the equipment of the canals has been carried out on a very complete scale, the use of locks is in many cases dispensed with, and hydraulic lifts are employed for the purpose of raising or lowering the heavy barges from one level to another. Lifts of this kind, which do not involve a serious loss of water, are installed at Les Fontinettes in the Pas de Calais, and at La Louvière in Belgium.

SUEZ CANAL.—The great networks of canals that now connect the industrial centres of all the civilized countries may be compared with the railway systems, with which they have to compete for the heaviest classes of traffic. They supply a ready, and in many cases a very cheap, means of transport, and to a large extent the industrial activity of many districts is dependent upon them. Other considerations than the direct earning power of the canal have determined the construction of certain large waterways, capable of passing modern vessels of the greatest draught. Of these the most important is the sea-level Suez Canal, which connects the Mediterranean with the Red Sea and provides the shortest and most convenient route to the countries of the East. When the proposed designs were considered by the original Commission appointed in 1855, it was decided to adopt a uniform depth of 26¼ ft., with a minimum bottom width of 144 ft. and a top width of 262 ft., but for financial reasons the bottom width was reduced to 72 ft. Since the construction of the canal the section of the waterway has been repeatedly enlarged, and work is now in progress which will in the near future ensure a depth throughout of over 34 ft., and an average bottom width of about 140 ft. Certain sections of the canal were formed by dredging, to the requisite depth, Lakes Menzaleh, Balah, Timsah and the Bitter Lakes, through which the canal passes, and an important feature of the system is the freshwater service channel, which it was necessary to construct alongside the main canal. From every point of view, whether political or commercial, the Suez Canal has proved itself to be an undertaking of the utmost value and importance, and one that has been an essential factor in the development of the Eastern trade.

MANCHESTER SHIP CANAL.—The Manchester Ship Canal connects Manchester with the sea, and makes it a port for the Lancashire area, with

its extensive network of inland canals. It is a purely commercial undertaking, and unlike other large waterways it has but little strategical importance. Up to the present time the construction and equipment of this great undertaking has involved an expenditure of about £10,500,000, and costly improvements are still in progress with a view to increasing the depth to suit vessels of 27½ ft. draught. At the present time the canal is regularly navigated by ships of 25½ ft. draught, the clearance under the keels being in such cases about 15 in. On the Manchester ship canal the fall to the level of the Mersey estuary is considerable, and the locks employed are of a very large size, both as regards change of level and capacity. Owing to the industrial nature of the country traversed by the canal, it has been necessary to provide numerous high-level and swing bridges, and at Barton, where the Bridgewater barge canal crosses the ship canal—but at a higher level—there is provided a swing bridge of a novel type. At each extremity of the bridge there is fitted a removable end, which can be lowered to prevent the escape of the water contained in the bridge section when the bridge is opened.

KAISER WILHELM CANAL.—In the case of the Kaiser Wilhelm canal, which connects the Baltic with the North Sea, the importance of the canal is largely strategic, as it provides for the German fleet, when in the North Sea, convenient communication with the naval station at Kiel, and with the dockyards on the Baltic. To some extent its strategic value had diminished within recent years owing to the limited width and depth, which were insufficient for battleships of the largest size, such as are now under construction in Germany; but 11½ million pounds have been voted to the improvement of the canal, and the work of increasing the depth and width is being actively pursued. The canal, which was commenced in 1887 and completed in 1895, connects the Baltic, at a point near Kiel, with Brunsbüttel, near the mouth of the Elbe, the length of the waterway being about 60 miles. Although the canal is essentially a sea-level one, it was considered advisable to provide tidal locks at the Baltic end for the control of not only the normal tidal oscillations, which amount to about 1 or 2 ft., but more particularly of the considerable variations of water level at the two ends of the canal, due to the piling up of the water by strong winds. It was estimated that the tidal gates would not require to be closed on more than thirty days each year; but experience has shown that even the slight current arising from the comparatively small diurnal differences of level seriously increases the difficulty of navigating the canal, especially when passing through the lock entrances, which have a width of 82 ft., and the gates are now always used for controlling the flow of the water.

PANAMA CANAL.—For more than half a century the problem of forming a passage way between the Caribbean Sea and the Pacific, for vessels of the largest size, has been considered in great detail and from every point of view, and vast sums have been expended from time to time in carrying forward the construction of the Isthmian canal, which was commenced by Lesseps about the year 1876. Other proposals have been made for the construction of a ship railway at Tehuantepec and for the driving of a large tunnel at Darien, but these schemes are chiefly remarkable

for their novelty. Apart from the great engineering difficulties that have to be surmounted in the construction of the Isthmian canal, the problem has until recent years been seriously complicated by political and other interests, and the failure of the original Lesseps sea-level scheme was brought about more by the operations of interested parties than through any insurmountable questions of design. In June, 1902, the United States Congress passed what is generally known as the Spooner Bill, which authorized the President to promote the construction of an Isthmian canal upon either the Nicaragua or the Panama route. This latter route closely followed the line of the original Lesseps canal, and was under the control of a French company, which had acquired the property after the failure of the Lesseps project. As a result of the negotiations of the Commission of which Admiral Walker was the head, the United States of America acquired, at a cost of 40,000,000 dollars, the whole property and interests of the French company; but the acquisition of the estate was not completed until the political stability was made secure by the formation of the Republic of Panama, which separated the canal zone from the Republic of Colombia.

In accordance with the requirements of the Spooner Act, President Roosevelt appointed a Commission to supervise the construction of the canal, which it was required should as far as possible follow the Panama route, and which should be "of sufficient capacity and depth to afford the convenient passage of vessels of the largest tonnage and greatest draught now in use, and such as may be reasonably anticipated". These conditions necessitated the construction of a canal of a considerably greater section than any proposed under the previous schemes, and it was decided to adopt a depth of 40 ft. Although the route was specified by the Spooner Act, the question of the actual design of the canal was left open, and, as expert opinions differed greatly, it was considered advisable by President Roosevelt to appoint an International Board of Consulting Engineers, whose function it was to consider the types proposed, and to advise him as to their respective merits. Of the thirteen members appointed, eight were representatives of the United States, while four were nominated respectively by the Governments of Great Britain, France, Germany, and Holland, and the fifth by the Suez Canal Commissioners. The majority of the board reported in favour of a sea-level canal, with tidal locks at the Panama end for the control of the tidal fluctuations, which sometimes amount to 20 ft. in the Bay of Panama on the Pacific side, and only 2 ft. in the Caribbean Sea. The minority of five members were in favour of a high-level canal with series of large locks, which were strongly objected to by the majority, on account of the difficulty and danger likely to be experienced in their navigation by large vessels, and on account of the ease with which the locks might be obstructed by an enemy or damaged by earthquake shocks. These objections, with the exception of the last, might however be advanced with equal reason in the case of the sea-level canal scheme, which, moreover, involved a longer time for construction; and for these and other reasons the scheme proposed by the minority was approved by the Isthmian Canal Commissioners, and sanctioned by the Government in 1906.

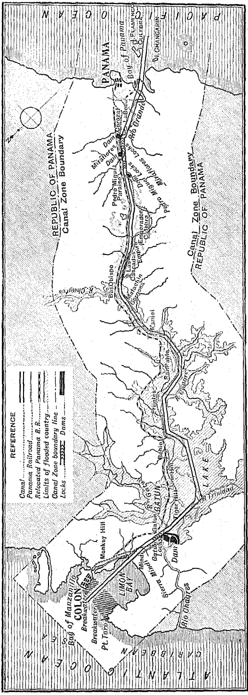


Fig. 607.—Map of the Panama Lock Canal

On the Isthmus of Panama the chief features are the Chagres River, the waters of which must be adequately controlled, and the mountainous country at Culebra, through which the canal must be cut for a distance of 7 or 8 miles; but although the quantity of material to be excavated is very great, no exceptional engineering difficulties have to be overcome, as in the construction of the large dams.

Under the sea-level scheme of M. Bunan-Varilla, which was recommended by the majority of the International Board, but not approved by the Canal Commission, it was proposed to construct a large tidal lock at the Panama end and to control the Chagres River by means of an immense dam at Gamboa, and by other dams of smaller dimensions. At the Culebra section it would have been necessary to cut down to a depth of 40 ft. below the mean tide level, a total depth from the summit of 250 ft., and the time required for the construction of the sea-level canal would have been largely determined by the progress that could have been made in the Culebra cut. As the Chagres River crosses the route, and as the bulk of its water under such a scheme must find its way to the ocean through the waterway, there would have been in the canal

a current of nearly $2\frac{1}{2}$ miles per hour; and as the course for a length of 19 miles comprises a number of curves, the navigation of the canal, so far as very large vessels are concerned, would not have been free from danger. Both schemes have undoubted advantages, and it would appear as if the decision to proceed with the construction of the locked high-level canal was determined largely by the questions of the cost and the time that would be required to complete it.

According to the locked-canal scheme (fig. 607), the Chagres River with its tributaries will flow into an immense lake, which will form the high-level link of the canal, extending for about 30 miles of the total length of 50 miles. It is proposed to construct the lake at a level of

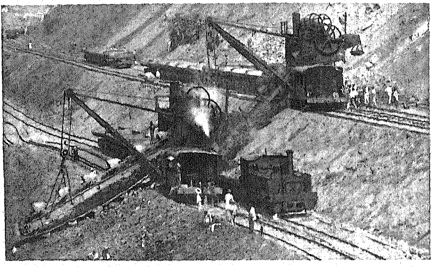


Fig. 608.—Old French Excavators at Work on the Panama Canal

85 ft. above the sea by placing a great earthen dam across the valley at Gatun, near the Atlantic end; and as the area flooded will be 160 sq. miles, the reserve of water will be amply sufficient, even in the driest season, for all probable locking requirements. Three other, but smaller, dams will be constructed near the Pacific end, and at some future date it is proposed to construct a large additional reservoir at Alhajuela, on the Upper Chagres. From these lakes an ample supply of water may be expected at all times, and where the canal passes through them the waterway will have a breadth of over 1000 ft. for more than one-third of the whole distance. Three equal pairs of locks, each 1000 ft. long and 100 ft. wide, will be constructed at Gatun, to raise the vessels in three stages through the height of 85 ft. from the sea level to that of the high-level lake, and the whole ascent will be made in a length of about 1 mile. At the Panama or Pacific end the descent will be made through similar locks, one at Pedro Miguel and two at Miraflores.

When the United States took over the property of the French company

the purchase price included the whole of the existing plant, but owing to the rapid deterioration which takes place under the tropical conditions existing on the Isthmus, much of the machinery had to be abandoned. The present American engineers testify, however, to the general excellence of the work of the French engineers and to the usefulness of their machines, many of which have been repaired and are now in constant service (fig. 608). Within recent years great improvements have been effected in the methods and the appliances used by the civil engineer. Hand labour, which was largely employed, especially in the latter stages of the French operations, has been superseded by more powerful and

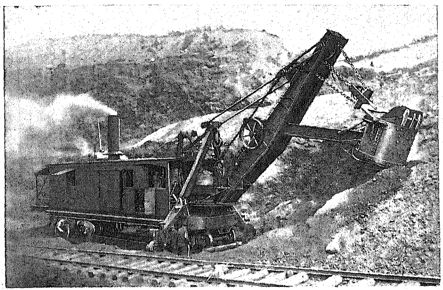


Fig. 609.—95-ton Steam Shovel at Work in the Culebra Section

efficient appliances. In the Culebra cut, the material, which is of too hard a nature to be excavated directly by the steam shovels, has to be brought down by blasting before it can be removed, but in the case of the powerful 95-ton steam shovels (fig. 609) the amount of blasting required is much less than in the case of the less-powerful shovels. Rock drills of very modern types are used for preparing the shot-holes, and the debris is loaded into the dump wagons of the train by the shovels, which are steadily advanced as the material is removed.

A work of the magnitude of the Panama Canal involves subsidiary works which in themselves are important undertakings. Throughout the entire route it has been necessary to establish railway communication for the transport of passengers and material, and the work of doubling the original track is being rapidly proceeded with. In addition, many miles of service tracks have to be continually laid and relaid to suit the progress of the work, and for this purpose special track-shifting

appliances have been devised by the engineers. Trouble is often experienced, especially in the rainy season, from flooding, and, apart from the time lost through interruption of the operations, the labour involved in repairing the damage done is frequently great. These engineering difficulties are, fortunately, not insuperable, and to overcome them is a question of time and money only. On the other hand, the construction of the canal has necessitated the solution of other problems of an economic and hygienic character. At the present time over 30,000 persons are engaged on the Isthmus, and the tropical conditions are such as to endanger the lives of even acclimatized persons It is doubtful whether the work could have been successfully prosecuted if the action of the Anopheles and Stegomyia in spreading malaria and yellow fever had not been discovered and the cure determined. Civilized life has been made possible in the city of Panama, where everything necessary for the health and well-being of the workers has been supplied; and one of the most important branches of this great work has been the establishment and equipment of efficient hospitals. Without these hospitals, and without the constant attention that is devoted to the health of the workers, the operations could not be carried on without the sacrifice of many lives.

CHAPTER XIV

AERIAL NAVIGATION: AIRSHIPS—HEAVIER-THAN-AIR MACHINES

INTRODUCTORY.—In attacking the problem of aerial navigation little assistance has been obtainable from a consideration of the experience obtained in other spheres, and to some extent the failures of pioneer investigators have been due to a too ready acceptance of theories deduced from the behaviour of bodies floating in other fluids, such as water. Probably the closest analogy to an airship is a submarine when running submerged, but the conditions are so widely different that the data gathered in the one instance cannot be usefully applied to the other. It is only the broad general principles that are common. Air near the surface of the earth has a density of about one eight-hundredth part that of water, and for equal buoyancy the volume of an airship must be correspondingly great. As a practical means of transporting merchandise the value of an airship is therefore negligible compared with that of a water-borne vessel. Apart from the question of density, air differs greatly from water in the nature, velocity, strength, and irregularity of the air currents, which may flow both vertically and horizontally, and which often are very different at different levels. Atmospheric currents are due to the expansion and displacement of large masses of air under the heating action of the sun and the earth, and considering the variable nature of climatic conditions it is improbable that they can ever be satisfactorily predicted. An airship, to

be of practical value, must be sufficiently powerful to advance against a wind current of average strength, and thus be independent of favourable currents which may possibly exist at some other level.

AIRSHIPS AND FLYING MACHINES.—There are two distinct questions involved in the problem of aerial navigation. The first of these concerns the upward movement of the body against the action of gravity, while the second concerns its propulsion through the air. There are, in addition, secondary questions of great importance, such as stability and control, but a first general distinction between aerial ships and flying machines can be based on the two main questions alone. In an AERIAL SHIP, such as the Zeppelin or the Lebaudy or the Parseval, the buoyancy is obtained by means of a light envelope filled with hydrogen or some other gas having a less density than air, while the propulsion is independently effected by means of an engine-driven propeller. In an AEROPLANE, on the other hand, the upward-lifting force is obtained dynamically as a result of the upward reaction on an inclined plane driven forwards through the air by a propeller. The support of the aeroplane machine in the air is thus dependent upon its forward motion, but it has been proposed, and at some future time it may become possible, to obtain the upward motion in the initial stage of the flight, by means of vertical propellers, flapping wings, or similar devices.

Since the floating power of the airship depends upon the displacement, by means of a gas-filled envelope, of a large volume of air, the weight of which necessarily equals the total weight of the ship, the term "lighter than air" is commonly applied to airships, to distinguish them from "heavier-than-air" machines of the aeroplane type, which are not dependent upon the use of a gas lighter than air.

AIRSHIPS

EARLY ATTEMPTS.—Although the possibility of aerial flight was foreseen by early writers of even the fourth century, it was not until the year 1783 that any actual results of practical importance were obtained, and it is doubtful if the imaginative schemes of the early philosophers were based upon any real knowledge of the fundamental principles of the problem. On the 5th of June, 1783, after several years of experimenting, two brothers, JOSEPH AND STEPHEN MONTGOLFIER, sons of a French paper manufacturer, succeeded in causing a large paper balloon filled with heated air to ascend to a height of over 300 yd., and from that date may be reckoned the commencement of the practice of aeronautics. In their earlier experiments steam, the newly discovered hydrogen gas, and smoke were each used for the inflation of their paper balloons, but without success. The steam at once condensed to water and allowed the air to enter, the hydrogen gas escaped immediately through the paper envelope, and the hot smoke quickly cooled. Success was only finally obtained by suspending under the open neck of the balloon a fire which maintained the high temperature and consequent low density of the enclosed air. Following the success of the Montgolfiers, Professor

CHARLES was enabled, by the public subscription of the people of France, to undertake extensive investigations, and to him is due the construction of the first hydrogen-filled balloon. On the 19th of September of the same year, 1783, a large Montgolfier balloon ascended from Versailles, carrying with it for the first time living creatures. After a flight of ten minutes the balloon sank gently to earth with its passengers—a sheep, a duck, and a hen—uninjured. About one month later, on the 21st October, PILATRE DE ROZIER and the MARQUIS D'ARLANDE made a successful flight in a very large balloon of the Montgolfier type, and to them belongs the distinction of having made the first aerial ascent. It is remarkable that Pilatre de Rozier was also the first victim, his death being caused by the explosion of his balloon, which was a highly dangerous combination of the Montgolfier and Charles types.

For many years balloons were solely used for meteorological purposes or for sport, and little development took place, but their value for war purposes was realized during the siege of Paris, where some use was made of them, and now the war balloon is an important part of the modern army field equipment.

CAPTIVE BALLOONS.—The motion of a free balloon carried along by the wind is remarkable for its stillness. There is no perceptible breeze and the only appreciable indication of the upward motion is the appearance of the receding earth or the internal pressure on the drums of the ears, due to the decreasing pressure of the air. In a captive balloon, which cannot move with the wind, the conditions are very different. A simple spherical balloon anchored by a rope gyrates, and is so unsteady generally as to make satisfactory observations a matter of great difficulty and discomfort. To overcome the rotary motion, long, cigar-shaped envelopes, held near one end, were introduced; but new difficulties had to be overcome, the chief of which was the danger of the balloon doubling up in the middle whenever, for any reason, the tautness of the envelope was not maintained. To preserve the form under all circumstances MAJOR VON PARSEVAL, in Germany, introduced within one end of the balloon a compensating balloon which could be expanded with air as required to compensate for any reduction in the volume of the gas in the main envelope. With such compensators or ballonets, which were first proposed and adopted by MEUSNIER in France, the outer form can be kept very rigid, and they now are recognized as an essential feature of any non-rigid or semi-rigid dirigible balloon which requires to be driven through the air. It was also found necessary in captive balloons of the cylindrical type to attach an external open-mouthed bag, which was expanded by the wind. This bag prevented the violent swaying of the balloon, which often was so great as to make the occupants of the car sick.

DIRIGIBLE BALLOONS.—A free balloon, unprovided with any means of propulsion, is at the mercy of the wind, and completely beyond the control of the aeronaut so far as direction is concerned. He may, by rising or falling to another level, find a favourable wind which will carry him in the desired direction, but even under the most fortunate conditions the possibility of reaching a predetermined destination is remote.

The free balloon is carried along by the wind, and, since there is practically no relative motion between the balloon and the air, any directional control by means of steering rudders is impossible, just as in the case of a boat the rudder has no effect unless the vessel is moving through the water, and not merely with it. It was recognized at an early date in the history of aeronautics that if a sufficiently light and powerful engine could be obtained, capable of driving the balloon through the air in which it floated, the problem of control would be overcome, and the remarkable advances that have recently been made are almost entirely due to the development of such a motor—the spirit-vapour internal-combustion engine of the motor car.

If the engines of a dirigible are capable of propelling it through still

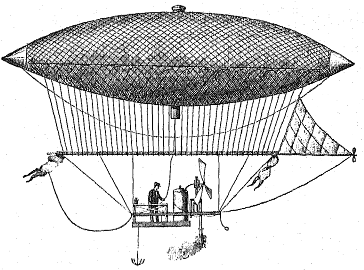


Fig. 610.—The Giffard Steam-propelled Non-rigid Balloon

air at a speed of, say, 10 miles an hour, it will be evident that the dirigible would be driven back by an opposing wind of any greater velocity, and since winds of greater velocity may be encountered during about 340 days of the year, the utility of such a low-powered airship is small. A considerably greater speed can only be obtained by means of engines of very considerably greater power, because not only is the resistance due to skin friction much greater, but the increased weight of the engines necessitates a gas envelope of larger size, and therefore greater resisting surface. The progress of the dirigible balloon has from the beginning been determined by the development of the propelling machinery, and the failures of the early experimenters were generally due to the excessive weight relatively to their powers of the engines then available.

In 1852 the engineer GIFFARD applied a steam engine to the dirigible balloon illustrated in fig. 610, and succeeded in advancing against a wind of over 6 miles an hour. Considering the weight of the engine, boiler, and other apparatus required, such a result was very satisfactory. DUPUY DU

LÔME, in the year 1872, completed a dirigible with which he hoped to communicate with the besieged city of Paris. Instead of using steam, he relied upon the muscular efforts of a number of men. His maximum speed did not exceed 5 miles an hour, and the endurance of the men did not permit of the speed being maintained for any considerable length of time. This balloon of Dupuy de Lôme is of considerable historical interest, chiefly on account of the triangular system of suspension links connecting the car to the envelope, a system generally adopted in modern dirigibles, and in the use of an internal compensator or ballonette, already mentioned in connection with the Parseval captive balloon. Electricity has also been used as the propelling force, but, considering the weight of the accumulators necessary for the power required, there is little prospect of success in this direction with the present means available. In the TISSANDIER balloon of 1883 a 1½-h.p. electric motor was used for driving the propeller, and a speed of 8 miles an hour was attained. In the following year a more successful balloon was constructed by two French army captains, REYNARD AND KREBS, who attained a speed of 14 miles per hour. At the trials, which were carried out in calm weather, the airship *La France* was steered back to the starting-point, and this is the first instance of the kind in the history of dirigible balloons. The accumulators and motors employed were of a special and much-improved kind, the weight per horsepower being less than one-half that of the Tissandier plant.

Notwithstanding the promising results obtained, it was evident that no great advance could be made until some powerful and more concentrated propelling system could be devised, and it is to the development of the motor-car type of internal-combustion engine that the recent advances are principally due.

TYPES OF MODERN AIRSHIPS.—Modern dirigible balloons, or airships as they are commonly called, may be classified under three general types, which differ from one another in one important feature, the rigidity of the gas envelope.

Upon this feature of rigidity of the envelope is based the classification of dirigibles into NON-RIGID, SEMI-RIGID, and RIGID balloons, each of which has certain advantages and disadvantages not possessed in the same degree by the others.

NON-RIGID BALLOONS.—As the name implies, the non-rigid type of balloon is dependent for its form upon the pressure of the gas, which keeps the envelope distended with sufficient tautness to enable it to be driven through the air at a considerable velocity, and the safety of the ship depends upon the maintenance of the form. The PARSEVAL DIRIGIBLE is typical of the non-rigid balloons, which it is claimed are particularly suitable for war purposes. It has the common cylindrical or cigar-shaped form of all airships, rounded or pointed at one end or both ends, the overall length being about six times the diameter. Internally there are provided two COMPENSATORS, which can be inflated by means of a mechanically driven fan or ventilator. As the volume of gas in the balloon diminishes from any cause, air can be pumped into the compensators, which occupy about one-quarter of the whole volume, to maintain the external form of the

envelope, upon which the safety of the non-rigid airship depends. The envelope is composed of a special rubber-texture fabric, applied in two layers of 3-ft.-wide strips arranged diagonally over one another. Externally the balloon is painted yellow to intercept the actinic sun rays, which have a deleterious effect upon the rubber. Along each side of the envelope are sewn strips to which the car suspension cords are attached, the weight being well distributed over the whole length. For lateral steering a vertical helm or plane, 80 sq. ft. in area, is hinged at the rear end to a fixed vertical plane of 200 sq. ft. area, which prevents any serious rolling of the balloon. Horizontal fins, each 172 sq. ft. in area, are also provided at each side of the rear end to diminish pitching, which if unprevented may jerk the car suspension ropes asunder. Several airship disasters have been attributed to the failure of the suspension, as a result of the severe stresses caused by the violent oscillation or pitching of the balloon. The propeller and engine are carried by the car, and the arrangement of the suspensions is such that the car remains level, even when the balloon itself is considerably inclined. The engine, which has six cylinders and is water-jacketed, weighs 770 lb., and develops 100 h.p. while running at 1200 revolutions per minute. The propeller has a diameter of 14 ft., and consists of a frame of hollow steel tubes covered with fabric.

As already stated, steering in the horizontal direction is effected by means of a vertical rudder at the rear end. Another method, however, is adopted for the vertical control of airships, which can be made to rise to a higher level, or fall to a lower, without need of throwing out ballast or losing gas. In all three types of airships the balloon is inclined by various means, and is driven by the propeller in an inclined direction to the desired level.

In the Parseval airship the inclination of the balloon is effected by transferring air from one of the internal ballonettes, say at the front end, into the compensator at the rear end, which thus becomes heavier and inclines the balloon upwards. As this operation of transferring air by means of the ventilator is not sufficiently rapid for certain emergencies, a shifting weight is provided for altering the balance, and therefore the inclination, of the balloon as required. The semi-rigid airships constructed by Lebaudy Frères, and the rigid airships of Count Zeppelin, are provided with horizontal steering planes; but use is also made, especially in the latter ships, of moving weights for controlling the balance.

SEMI-RIGID AIRSHIPS.—In the semi-rigid type of airship the under side of the balloon consists of a flat rigid framework, to which the stability planes are attached, and from which the car with its engine and propeller is suspended. In this way a more uniform and definite distribution of the weight over the balloon is obtained without the use of a network of cordage, which greatly increases the skin friction. The semi-rigid type of airship is chiefly advocated in France, and much of the progress that has already been made in the science of aerial navigation by means of dirigibles is due to the perseverance and ingenuity of such French engineers as M. HENRI JULLIOT, who has designed and constructed numerous ships for LEBAUDY FRÈRES.

In November, 1902, M. Julliot, in conjunction with M. Lebaudy completed an airship which fully realized the expectations of the designer and attained a speed of nearly 25 miles an hour. The *Lebaudy I*, as the ship was called, was unfortunately torn from its field moorings during a heavy gale in the summer of 1906, and was totally wrecked. A second ship, the *Lebaudy II*, was built with the assistance of the French military authorities, to whom it was ultimately presented, and at a still later date *La Patrie*, which was also lost in a gale, was constructed upon the same general lines. Disaster again followed the French efforts when the still more recent airship, the *République*, was lost, together with its crew, through the

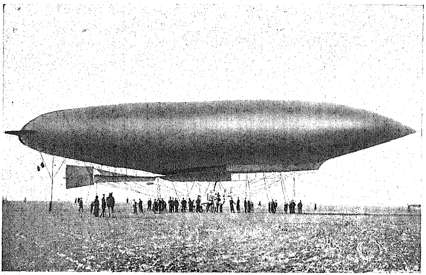


Fig. 611.—*The Lebaudy II* Semi-rigid Dirigible Balloon

accidental fracture of a propeller blade, and the consequent rupture of the balloon envelope.

In fig. 611 is illustrated the *Lebaudy II*, which is typical of the semi-rigid system. The illustration clearly shows the arrangement of the vertical and horizontal steering and equilibrium planes. The gas bag is cigar-shaped, and has an overall length of six times the diameter. At the forward end the envelope is sharply pointed to facilitate the quiet displacement of the air during flight, but at the after end a rounded form was adopted to provide the required support for the rear planes. At the base the envelope is attached to the rigid frame already mentioned, from which the car is suspended. Two propellers are employed, one on each side of the car, where the disturbance of the air is small, and a petrol motor is used for driving them. The petrol storage tank is shown in the illustration, suspended immediately under the rear horizontal plane, where it is far removed from the hot engine and possible danger of ignition.

Non-rigid and, to a lesser extent, semi-rigid balloons have the great advantage of portability, which for war purposes is an essential feature.

The gas bag, when deflated, and the parts of the car and the engine can be readily transported to the nearest balloon station, if for any reason an unexpected landing becomes necessary. Balloons of these types suffer, however, from the serious disadvantage that their safety is dependent upon the tautness of the envelope, and therefore upon the efficient working of the ballonette fan. If by accident the fans should become deranged, a landing would probably be necessary to avoid disaster, and in the case of a war balloon the landing might have to be made in the territory of the enemy. At the present time a large airship cannot be brought to the ground at places where efficient mooring facilities are not provided without great risk

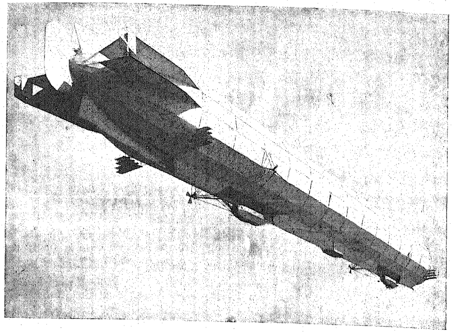


Fig. 612.—The Zeppelin Rigid Dirigible Balloon

of destruction, especially if the landing has to be made in the neighbourhood of trees.

RIGID AIRSHIPS.—The numerous disasters that have occurred to French airships have generally resulted from a compulsory landing under unfavourable circumstances, and from the absence of sufficiently strong moorings. The rigid type of balloon, with which the name of COUNT ZEPPELIN is so closely associated, has the advantage that its rigid form is not dependent upon the working of any mechanical fan, which may become deranged. It is exceedingly cumbersome on the other hand, and lacks the portability necessary for military purposes. For these and other reasons the German military authorities have not yet adopted the Zeppelin rigid balloon, which is illustrated in fig. 612. The balloon consists of a rigid aluminium framework stayed with steel wire, of the form shown in the

illustration, which represents the 1908 model. Externally the framework is covered with a waterproof fabric, which protects the framework and the separate balloons contained within its seventeen compartments. It is claimed by Count Zeppelin that the safety of the airship would not be endangered if one of the ballons was completely emptied of its gas. The overall length of *Zeppelin II*, as the 1908 model was called, was 136 m. Its diameter was 13 m., and the cubic capacity was about 15,000 c.m. Owing to the use of the metal framework and the outer cover, a large displacement was necessarily required to obtain the desired buoyancy. A feature of the Zeppelin airship is the duplication of the cars and of the propelling machinery. The two cars and engines are arranged near the two ends of the ship, and each engine drives two oppositely rotating propellers, one on each side of the ship. If for any reason one of the engines cannot be used, the other is still able to drive the ship but at a greatly reduced speed, at which the manœuvring power is correspondingly less. In the earlier Zeppelin model the insufficient power of one engine working alone was the direct cause of the loss of the ship, which was compelled to land under unfavourable conditions. In the 1908 model each of the two engines had a horse power of 110, and in the still more recent ship, *Zeppelin III*, a third engine was installed. The cars are connected by a covered gangway, which also serves as a track for a movable balance weight, by means of which any considerable change of balance can be adjusted. Objectionable rolling is prevented by the large projecting fins shown in the illustration, and horizontal steering is effected by means of the large central rudder and the pairs of double vertical planes pivoted between the fixed horizontal stability planes.

For steering in the vertical direction there are provided sixteen planes, arranged in sets of four on each side of the front and rear ends of the balloon. The British Naval Airship No. 1, built by Messrs. Vickers, Ltd., closely resembles the Zeppelin ships, but no satisfactory results have yet been obtained although much valuable experience has doubtless been gained. Airships have proved to be too cumbersome, unreliable, and expensive for practical requirements, and at the present time attention is being concentrated upon the development of aeroplanes.

HEAVIER-THAN-AIR MACHINES

ADVANTAGES AND LIMITATIONS.—In the heavier-than-air type of machine a dynamical solution of the problem of flight has been obtained. The materials used in the structure are throughout heavier than air, and the weight is sustained in the most successful arrangements by the reaction of the air upon the plane surfaces of the machine driven at a considerable speed through the atmosphere. There is no cumbersome and vulnerable gas envelope required, and one of the chief advantages of the flying machine, as compared with the airship, is the simplicity and cheapness of its construction. The flying machine cannot, however, be looked upon as a substitute for the airship, which possesses several essential features of importance not readily obtainable in the flying machine,

and it is possible that, as the result of future experience, the serious objections to airships may be overcome.

The number of passengers or the load that can be carried by an aeroplane is limited by the supporting surface of the planes and the power of the engines, which determine the speed of propulsion and the lifting force, and few machines at present in use carry more than one passenger along with the operator. Additional lifting power is obtainable by an increase of the lifting-plane area, provided the speed is not correspondingly reduced; but the frictional resistance of the additional structure necessitates an increase of engine power and weight, which in turn necessitates a further considerable increase of the lifting area. With engines of the present-day construction an increase in the number of passengers would necessitate a large increase of the size of the machine, and the present advantage of lightness and portability would thus be lost to a large extent. Additional lifting power is also obtainable by increasing the speed of propulsion, and thereby the vertical component of the reaction on the lifting surfaces; but the frictional resistance to the motion is directly proportional to the speed, and a more powerful and heavier engine is as before involved.

Unlike the airship, the flying machine suffers from the serious disadvantage that it cannot remain stationary in the air, although to some extent the same effect may be obtained by circling around the position. If the engine is stopped, the machine glides downwards to the earth, since its lifting power is dependent upon its forward motion. A further disadvantage of the aeroplane is that it must be propelled along the ground until the speed at which the machine rises is attained, and that it cannot therefore rise from a restricted position. When more powerful and lighter engines are available, it is possible that this disadvantage may be overcome by the provision of vertical lifting screws or other devices.

TYPES OF HEAVIER-THAN-AIR MACHINES.—Heavier-than-air machines may be divided into three classes, generally known as orthoptères, helicoptères, and aeroplanes. The ORTHOPTÈRES are provided with wings which are made to beat the air in imitation of the action of large heavy birds. Attention is again being devoted to this type of machine, which would make hovering possible, and already promising results have been obtained.

In the HELICOPTÈRE system the lifting force is obtained by means of screws capable of rotation around a vertical axis; and to prevent the body of the machine itself from rotating, the vertical shaft is provided with two oppositely rotating screws, or, when single screws are used, a large vertical plane is fitted to the body. Although the power of rising upwards from the ground is very desirable, it is still more desirable that the flying machine should be capable of advancing, and to do this effectually separate propellers and engines would be required. It has been proposed to avoid the use of an additional engine by providing means whereby the propeller may be inclined in the desired direction of flight, but no successful results have been obtained with machines of the helicoptère type. It is probable that at some future time, when improved propelling machinery

is obtainable, successful results may be obtained by a combination of the helicoptère and the aeroplane systems.

AEROPLANES.—At the present time the efforts of experimenters are mainly directed towards the development of the aeroplane type of flying machine, from which the most promising results have been obtained, and it is fortunate that the development is not confined to one particular construction. From the study of the behaviour of simple kites and of the more complicated cellular kites of Hargreave much valuable information has been obtained regarding the action of currents of air upon inclined planes, but it is to Professor LANGLEY, of America, that the first exhaustive investigation of the subject is due. Certain of the conclusions of Langley have proved, however, to be erroneous, such, for example, as the conclusion, generally known as Langley's law, that the tractive force required to propel an aeroplane at a high speed was less than at low speeds. This so-called law was based on the assumption that the frictional resistance of the air at the surfaces of the planes was negligible, whereas in reality it is very considerable, and at least one hundred times what was at first supposed. When an inclined plane is driven, say, horizontally through the air, the normal pressure of the air on the plane may be resolved into a vertical or lifting component, and a horizontal component which opposes the forward motion. As the inclination of the plane is diminished the vertical component increases and the horizontal component decreases, and if the frictional resistance were negligible the resistance to the motion would vary as the inverse square of the velocity of propulsion, as was assumed by Langley. The frictional resistance is, however, considerable, and in reality the power required for the propulsion of an aeroplane increases directly with the velocity.

Before the introduction of light powerful motors much valuable experience was accumulated by a few daring experimenters, who succeeded in gliding through the air from an elevated starting-point while supported by large plane surfaces. In 1854 CAPTAIN LEBUS succeeded in making and actually using a gliding machine, but an accident, which resulted in a broken leg, terminated his experiments. Other experimenters carried on the work, notwithstanding the great dangers incurred, and from about the year 1890 successful flights were made by a Berlin engineer, Herr LILIENTHAL. The apparatus devised by Lilienthal consisted of large wings arranged around his body, as shown in fig. 613, and his flights were made from the top of a small specially constructed hill, from which he glided downwards in some cases over a distance of 300 yd. To preserve the balance of the machine the lower portion of the body and the legs were swung to one side or the other as required, and upon the skill and experience of the operator in correcting sudden variations of the equilibrium depended the success of the flight. In later machines Lilienthal adopted a system of superposed planes resembling the modern aeroplane construction. The promising career of this experimenter was brought to an untimely end in 1896 by a sudden downward swoop of the apparatus. A similar accident, which also resulted in the death of the operator, befell MR. PERCY PILCHER, who had continued in this

country the work of Lilienthal, and who was about to apply a specially designed petrol motor for the purpose of driving his machine. CHANUTE, in America, during the years 1895 to 1897, made numerous flights with various types of gliding machines, some of which had as many as six superposed planes. He ultimately returned to the simpler form of two planes, either superposed or one in front of the other, resembling to a remarkable extent the aeroplanes of the present time.

SIR HIRAM MAXIM, in England, carried the problem a step further in 1894 by constructing a particularly light steam engine and boiler which he

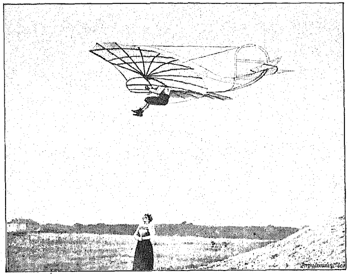


Fig. 613.—Lilienthal's Gliding Aeroplane

applied to an aeroplane. The machine was mounted upon wheels and driven by an air propeller along a special railway, but it was prevented from soaring by means of guard rails arranged above the tops of the wheels. It was conclusively proved that the machine was capable of lifting its own considerable weight, and finally the machine broke through the upper guard rails and wrecked itself upon the surrounding trees. With the introduction of the still lighter petrol motor the greatest difficulty in the way of aerial flight disappeared, and it is to the advent of the petrol motor that the remarkable progress of recent years is due.

TYPES OF AEROPLANES.—The aeroplanes of the present day may be grouped according to the number of the supporting planes; but this classification is more convenient than rigid, especially in the case of biplanes, which might be more scientifically classified according to their degrees of automatic stability. It was at one time thought that the greater the number of superposed planes the greater would be the stability of the machine, and aeroplanes having five or six were constructed. Owing, however, to the great resistance to the motion offered by the surfaces

and the framework, the number of superposed planes in the machines of the present time rarely exceeds two.

BIPLANE MACHINES.—There are now numerous forms of biplane machines, differing from one another in many cases in the details of construction only, and it will be sufficient therefore to describe the principal typical machines.

In fig. 614 is illustrated the aeroplane of the brothers WILBUR AND ORVILLE WRIGHT, of Dayton, Ohio, U.S.A. These successful pioneers conducted their experiments and trials and gained their skill under conditions of considerable secrecy and full confirmation of the results reported

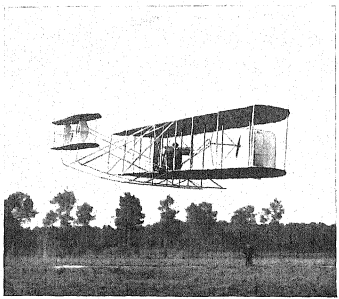


Fig. 614.—The Wright Biplane Machine

from America was not publicly obtained until the efficiency of their machine was thoroughly demonstrated in France. The Wright machine consists of two narrow planes of 60 sq. yds. sustaining surface connected together by light vertical hickory-wood struts stiffened by means of a system of steel wires under tension. A pair of launching runners projecting forward from the under side of the lower plane serves also for the support of two small horizontal planes, which can be inclined upwards or downwards to control the vertical motion of the machine. At the rear end is attached a similar pair of vertical planes or rudders, the movement of which controls the horizontal direction of the motion. Two large-diameter propellers placed behind the main planes are used for the propulsion of the machine, and the motor from which they are chain-driven is carried upon the framework of the lower plane and runners. The positions of the motor and of the operator are so arranged on either side of the longitudinal centre line that the balance of the machine is not

affected, and when it is desired to carry a passenger a seat is provided on the centre line.

By the Wright brothers it is considered advisable to provide two propellers, which are driven in opposite directions, to prevent any disturbance of the lateral balance of the machine during flight. This opinion is not generally shared by other constructors, and single propellers are now commonly used with successful results. There is, indeed, a strong objection to the use of two propellers, owing to the unbalanced conditions that arise when by accident one of the propellers becomes deranged, and on two occasions serious accidents of this kind have befallen both brothers. The Wright machine differs from the typical French machines in one respect of considerable importance. The design of French aeroplanes is such that their stability is more or less automatically maintained during flight, but in the Wright machine the use of any cellular arrangement of the main planes and the tail, which conduces to automatic stability, is purposely avoided, as the designers consider the control of stability should depend entirely upon the skill of the pilot. This control is provided in a very simple and ingenious manner by making the rear corners of the supporting plane flexible, and providing means for warping them. If, for example, the machine inclines suddenly downwards on the right side, the operator bends the right-hand corner downwards and the left corner upwards, and the reaction of the air on these curved portions then causes the right-hand side to rise and the left side to sink until the warping of the planes is discontinued. As the action of the warping planes tends to alter slightly the lateral direction of the motion, the warping lever is so coupled to the vertical rudder that the latter is displaced sufficiently to correct the tendency.

In one other respect the first Wright aeroplanes differed from those of French design, namely, the method of launching, and in this regard the utility of the Wright machine appeared to be limited, since a special arrangement of launching rails was required. The launching apparatus consisted of a wooden tower at the starting end of the railway, and of a weight of about ½ ton suspended from the top of the tower. The suspension rope was led downwards over pulleys, then horizontally to the front end and back to the inner end of the railway, where it was attached to the aeroplane, the runners of which rested on the ways. To launch the machine the propeller was first set in motion, and then the suspended weight was released. The falling weight towed the aeroplane forward with a velocity sufficient to cause it to rise in the air clear of the launching ways and of the tow rope. All aeroplanes are now provided with a chassis upon which the machine is propelled along the ground until it rises, and it is therefore possible, without special preparation, to start from any position where the ground is sufficiently flat and unobstructed. In soft ground serious accidents have resulted from the sudden stoppage of the forward motion due to sinking of the wheels into the ground, and in certain designs a combination of the runners and of the wheels has been adopted.

The Wright machine, which weighs about 1200 lb., is remarkable for

its general efficiency, the power of the engine being about one-half of the power required in certain of the French designs. This result has been chiefly obtained by the careful design of the planes and of the propellers, which run at a comparatively slow speed of 450 revolutions.

In France the firm of VOISIN FRÈRES have endeavoured to make the stability of their machines independent to some extent of the skill of the operator, and their success, in at least calm weather, is evident, from the ease with which a novice can learn to control aeroplanes of their design. A certain amount of stability is obtained in all biplanes by making the supporting planes long transversely and narrow. In addition, Messrs. Voisin make use of the cellular arrangement of planes advocated by Hargreave, Chanute, and other experimenters. The arrangement of

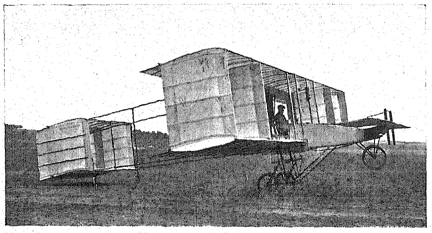


Fig. 615.—The Voisin Biplane Machine

the vertical planes between the main supporting planes and the position of the cellular balancing tail are clearly shown in the side view of the Voisin machine (fig. 615), which also shows the front steering plane for controlling the elevation and at the bottom the chassis. The sustaining planes have an area of 60 sq. yd., and the total weight of the machine in flying order is about 1200 lb. The engine develops about 50 to 60 h.p., and the two-bladed propeller, of about $6\frac{1}{2}$ ft. diameter, runs at a maximum speed of 1100 revolutions per minute. M. FARMAN has modified the Voisin machine, as shown in fig. 616, by dispensing with the vertical planes and thus abandoning the idea of automatic stability. Instead of the warping planes used by the brothers Wright for controlling the lateral stability, he has adopted the system of small movable planes or AILERONS shown in the illustration. By dispensing with the vertical surfaces a considerable reduction of the skin friction is effected, and a higher speed is attainable as compared with the Voisin machine, which for the same sustaining power requires 12 sq. yd. additional sustaining surface.

MONOPLANES.—In the early experimental apparatus of Professor

Langley two planes were used, but instead of being superposed they were placed in tandem, and to improve the stability each plane was slightly V-shaped with respect to the longitudinal central line. This

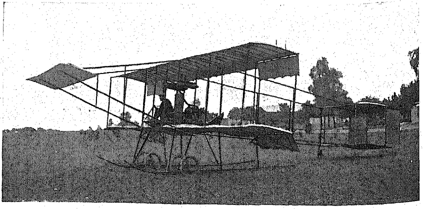


Fig. 616.—The Farman Biplane Machine

tandem arrangement has been retained in the modern monoplane designs, but the rear plane is made small and serves for the control of the elevation, and a small vertical plane is provided for the horizontal control. Owing to the reduction of the framework as compared with the biplane the

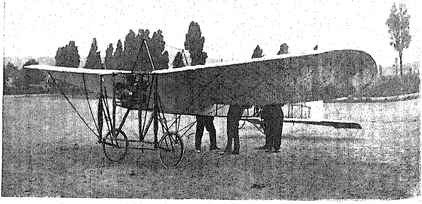


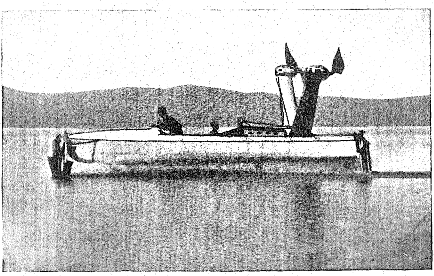
Fig. 617.—The Blériot Monoplane

skin friction is reduced, and thus greater speeds and reduced weights are possible. The monoplane of M. Blériot is illustrated by fig. 617. It will be seen that the front plane is considerably curved and the rear plane slightly curved. The weight of the engine and of the chassis lies below the level of the supporting planes, and the lowness of the

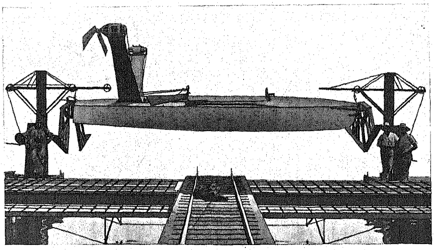
centre of gravity partially accounts for the stability of the monoplane. Means are provided for altering the V formation of the main supporting planes, and thus controlling the stability. The monoplane used by M. Blériot in crossing the English Channel for the first time in 1909 was provided with a total sustaining surface of 17 sq. yd., the spread of the wings being about 25½ ft. and the breadth 6 ft. A three-cylinder Anzani petrol motor of 22 b.h.p. was used for driving the two-bladed propeller at a speed of about 1200 to 1400 revolutions per minute. The total weight of the machine, including the operator and a supply of petrol sufficient for the passage, was about 600 lb., of which the motor weighed 132 lb. The distance traversed in the flight is estimated at 26 miles, and, as the time taken was thirty-five minutes, the average speed was about 45 miles per hour. In the unsuccessful attempt of MR. LATHAM to equal M. Blériot's performance the machine used was a monoplane designed by M. Levavasseur of the Société Antoinette. In general arrangement the machine resembles to some extent that of M. Blériot, but for the control of the lateral stability two ailerons are provided. Metal is largely used in the construction instead of ash and poplar as in the Blériot design, and the weight is accordingly considerably greater. In Mr. Latham's second attempt to cross the Channel an engine of 100 h.p. was substituted for the previous Antoinette engine of 50 h.p. It is estimated that the speed attained exceeded 60 miles per hour.

The further development of flying machines, whether of the biplane or of the monoplane type, largely depends upon the improvement of the engines, the weight of which in relation to their power is still greater than is desirable. In the attempt to reduce weight the reliability of the engine has been affected, and in many cases the cylinder-cooling water system is dispensed with and the less efficient air-cooling system substituted. In all machines it is at the present stage considered necessary to avoid the use of a clutch between the propeller and the engine, owing to the weight of such gear, and when starting, the inconvenience involved is considerable. Many of the minor difficulties, such as are experienced in the use of the carburettor, are being rapidly overcome, and there is every reason to expect that, as the number of experienced designers engaged in the work increases, the power of the engines will be increased and their weights reduced.

HYDROPLANES.—Numerous interesting experiments have been carried out to determine the best form and efficiency of propellers working in air, and certain of the results obtained are remarkable. With an air propeller fitted to a motor bicycle and driven by the engine, M. Archdeacon was able to travel at a speed of 49 miles an hour, and in similar experiments carried out upon an air-propeller-driven boat a speed of 43 miles per hour was obtained with a Clement Bayard engine of 80 h.p. The Crocco and Ricaldoni Hydroplane boat referred to is shown, in the Plate, travelling on the surface of the water. As the speed of the propellers is increased, the boat rises out of the water upon the inclined V planes at the bow and stern until, when travelling at over 40 miles per hour,



The boat is driven by aerial propellers, on the surface of the water, at a speed of about 15 miles per hour. The hull rises clear of the water on the bow and stern V-planes. A speed of 43 miles per hour has been attained on calm water.



The boat suspended from the launching davits over the water. The V-planes at the stern are more widely spread than at the bow, and are not joined at the apex of the V.

THE CROCCO AND RICALDONI HYDROPLANE BOAT

the bottom of the boat is about 18 in. clear of the surface, and it has been found that waves of 7 in. height do not seriously interfere with the action. The general arrangement of the hydroplane type of vessel will be more clearly understood from the illustration, which shows the boat suspended clear of the water.

CHAPTER XV

WARSHIPS

INTERNATIONAL RELATIONS.—Modern civilization is the result of the active enterprise of rival nations whose efforts, although directed to the furtherance of their individual interests, have of necessity determined the progress of the whole world. But the growth of international commerce and the need of further outlets for expansion have brought the interests of rival countries into serious conflict, and have made the possession of means of defence and of coercion essential to the existence of a nation. These are the conditions of present-day life, and whether warfare will be superseded in the future by more humanitarian methods of adjusting the international differences that arise is a speculative question that cannot be discussed here. Some progress has, however, been made as a result of certain treaties and conferences in establishing international laws which prohibit the use of barbarous and extreme methods of warfare and which protect the interests of neutral powers, but the results of the last Peace Conference, which was attended by the representatives of forty-five nations, do not indicate any immediate prospect of the establishment of an effective international court of arbitration.

Certain of the smaller powers are dependent, so far as their independence is concerned, upon their political position between the greater powers, and in such cases the necessity for costly defences does not exist. Larger powers have, on the other hand, to maintain strong armies and navies in a state of high efficiency for the protection of their commerce and for the defence of their rights. Military warfare still demands, as in olden times, the employment of large bodies of men, but great improvements have been effected in the methods of handling the armies and in the power and efficiency of their appliances.

WAR VESSELS.—In naval warfare, on the other hand, machinery plays an all-important part, and the men employed are skilled in its control more than in the art of individual fighting, such as is met with in the armies. A modern battle fleet comprises various distinct classes of vessels, each designed for a particular service, but within recent years the distinction between several of these has become one of name only. Thus the heavily armed and armoured cruisers of the British *Lion* class might equally well be placed in the first fighting line although their armour protection is somewhat inferior to that of the most recent

battleships. The terms *Dreadnought* and *Super-Dreadnought* are commonly used to designate all heavily-gunned ships of the *Dreadnought* and more recent classes.

The BATTLESHIP is primarily intended for the severest work of an engagement, and is accordingly heavily armed and protected, whereas the CRUISER is specially fitted to undertake the duties of skirmishing, and is therefore provided with the greatest possible speed obtainable by a reasonable reduction of armament and protection. As has been already mentioned, the most recent British cruisers have, however, an armament and protection that are not greatly inferior to those of many first-class battleships. A special type of vessel has been developed for scouting purposes, and these ships are generally lightly-armed vessels of very high speed, while for night attacks there is provided the TORPEDO BOAT. The use of torpedo boats has necessitated the employment of TORPEDO-BOAT DESTROYERS of sufficient speed and power to overtake and destroy the torpedo boat, but the two classes are now almost entirely merged. Since 1886 the French naval authorities have been actively engaged in experimenting with various types of SUBMERSIBLES and SUBMARINE BOATS, but it was not until 1900 that the British Government commenced to build these vessels, which are now being made in considerable numbers. The first French submarine, the *Gymnote,* designed by M. Gustave Zédé, is still in existence, but its torpedoes have been removed, and the vessel is now used for experimental purposes only.

The value of the submarine is supposed to consist more in the moral effect its presence is likely to have upon the enemy than in the results of its attack, which at the present time cannot be directed with any great certainty of success and safety. It was rumoured that submarines were employed in the Russo-Japanese war, but it has since been authoritatively stated that submarines were at no time engaged, so that the actual value of such craft in warfare has still to be determined. At the time of the war Russia had at Port-Arthur no submarines suitable for the defence of the harbour, and those at Vladivostock had no opportunity of operating. It was also reported that none accompanied the fleet of Admiral Rojdestvensky to the East. Several were under construction in Japan, and parts of others were shipped from America for erection in Japan, but war was concluded before any one of these vessels was completed.

MINES AND BALLOONS.—The value of FIXED and FLOATING MINES for the protection of the harbour entrances and other narrow waters was again fully proven in the case of the Russo-Japanese war, when both sides suffered heavy losses from accidental contact with these destructive weapons. Floating mines were sown widespread by both parties, but the destruction was not confined to the ships of the belligerents, and two years after the conclusion of the war the menace of these derelict mines to shipping still continued in the Japanese and Yellow Seas. Ordinary CAPTIVE BALLOONS were used during the war for observation purposes, but no experience of dirigible balloons and airships was obtained. In the conflict between Italy and Turkey it is reported that valuable scouting work has been done by Italian aviators using aeroplanes.

Transport Vessels.—In the event of war it is essential that there should be an immediate and ample supply of merchant vessels suitable for transport and similar purposes, as was the case during the South African war, when large numbers of men and great quantities of supplies had to be transported without delay. By special arrangement with the leading shipping companies the necessary ships can at once be obtained when the necessity arises, and in the case of such express vessels as the subsidized liners the *Lusitania* and the *Mauretania* special provision is made for arming them with light guns.

Types of Battleships.—In the British and other navies the fighting ships of the fleets belong to distinct classes, each class being in general an advance so far as armament, protection, and speed are concerned, upon the earlier ones. Thus the *King Edward* class, commenced in 1902, comprises eight vessels built, except in minor details, to the same specification, and armed alike. These vessels have a main armament of 12-in. and 9.2-in. guns, and a secondary armament of 6-in. and 12-pounder guns, whereas in the previous *Queen* class there are no 9.2-in. guns. In the *Lord Nelson* and *Agamemnon* of 1908 and 1907 the 6-in. guns were dispensed with, and a larger number of 9.2-in. guns were provided, while the secondary armament, intended chiefly for repelling torpedo-boat attacks, is composed of fifteen 12-pounders and a number of lighter weapons carried upon a light superstructure, which offers, however, a considerable target to the enemy. There is some doubt as to the suitability of 12-pounders for the purpose of repelling torpedo-boat attacks, and the later ships are provided with the heavier 4-in. gun. Although the two ships of the *Lord Nelson* class are more powerful in all respects than any of the earlier vessels, they resemble them to some extent, and may be considered a development of one type. In the still more recent *Dreadnought* class a marked departure from previous practice has been made as a result of the adoption of what is popularly known as the "all-big-gun" armament. Each ship of the class carries ten 12-in. guns, and no other sizes are provided, with the exception of a light secondary armament, consisting, in the case of the *Dreadnought*, of 12-pounders, and in the later improved *Dreadnoughts*—the *Bellerophon*, the *St. Vincent*, and the *Neptune*, *Colossus*, and *Orion* classes—of 4-in. guns. In the *Orion* and *King George* classes ten 13.5-in. guns are mounted in five turrets arranged on the centre line, and in the latter ships it is stated that the secondary armament may comprise twenty 4.7-in. guns. The centre-line arrangement enables all the heavy guns to be fired on either broadside.

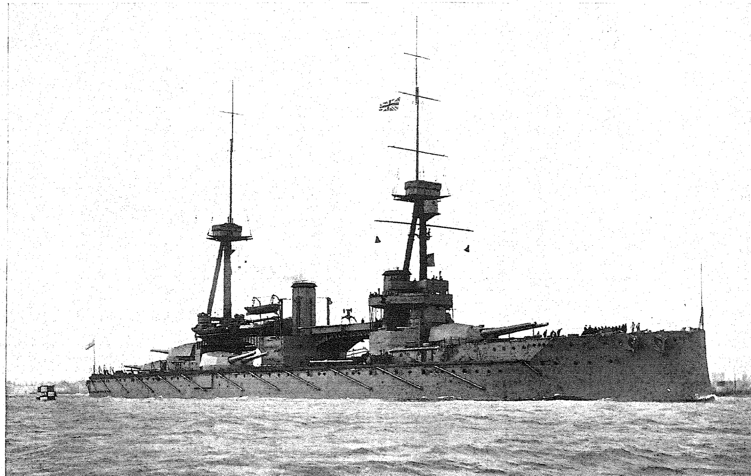
Other nations have found it desirable to adopt the "all-big-gun" type of battleship with, in some cases, modifications. Thus it is reported that the recent Japanese ships will carry fourteen 12-in. guns in addition to a secondary armament of ten 6-in. and a number of 4.7-in. guns. Three 12-in. guns will be mounted in the forward and three in the after turret. It is possible, however, that the triple turrets may not be adopted.

The Japanese *Dreadnought* cruiser being built by Messrs. Vickers, Ltd., will carry eight large guns of 13.5-in. calibre, and the displacement will be 27,500 tons. With turbine machinery of 80,000 h.p. it is anticipated that

a speed of 25 knots will be attained. No particulars have yet been published regarding the disposition of the gun turrets. The Italian government has definitely adopted triple turrets, and in the *Dante Alighieri*, launched in August 1910, there are four centre-line turrets, each carrying three 12-in. 46 calibre guns. Triple turrets are also under consideration or have been already definitely adopted by the United States of America, Russia, and other foreign powers.

The structure of a battleship is designed to carry the guns and also the armour, which protects not only the crew but primarily the vitals of the ship, such as the magazines, the engines and boilers, and the guns. In the design of a ship of a given displacement the best compromise has to be made between the size, and therefore weight, of the guns and mountings and of the armour, which must be disposed to the best advantage. The heaviest armour, varying in thickness from 10 to 12 in., is placed as a belt extending amidships on each side, so as to protect the engine and boiler spaces; and the depth of the belt is generally such that its upper edge does not sink below the water level when the ship is very heavily laden with stores and coal, as might happen in actual war at the commencement of a long voyage. On the other hand, the depth of the belt should be such that it does not rise above the water level and expose the lower unprotected portions as the stores and coal are consumed. Towards the forward and after ends of the ship a lighter armour of from 2 to 6 in. has to be used in order to economize weight, and these parts of the ship are therefore reserved for storage and other purposes, the vital machinery and magazines being concentrated within the heavily armoured spaces and under the armoured deck, which occupies a position approximately level with the water. The sides of the armoured deck, varying in thickness from $1\frac{1}{2}$ to $2\frac{3}{4}$ in. in the *Dreadnought*, are sloped downwards below the water level, so as to present an upwardly inclined surface to any shell that may penetrate the main armour. Additional protection is obtained from the coal stored in the bunker spaces behind the armour. A shell which pierces the outer armour has then to pass through the coal and through the protected deck before it can reach the machinery or magazines. The main guns are mounted generally in pairs in specially armoured turrets upon the upper deck, and for these armour of from 12 to 14 in. is frequently used, and similar protection is provided for the forward main conning tower, from which the ship may be operated in action.

By means of longitudinal and transverse bulkheads the whole underwater space of the ship is subdivided into water-tight compartments, and the arrangement is such that the flooding of one or two of these will not seriously endanger the buoyancy; but the loss of certain ships has resulted from the heeling over of the vessel to a dangerous extent, as a result of the flooding of compartments on one side of the ship only. Provision is now made for connecting the compartments on opposite sides of the ship, so that when necessary the trim of the vessel may be restored. Until recently it has been customary to provide doorways between adjoining compartments, with special arrangements for closing them from positions



E. W. C. Hopkins, Southsea

H.M.S. NEPTUNE

above the protected deck. These openings are, however, a source of considerable danger, and instances of disaster from the failure to close completely the water-tight doors, either through negligent omission or by reason of some obstruction, are not uncommon. In the most recent ships no intercommunications are provided, and access to each compartment can only be obtained from an upper level. This involves considerable inconvenience in the ordinary working of the ship, but the question of complete safety is rightly considered to be of first importance. Pumps are installed for dealing with minor leaks, and the actual flooding of a compartment is only likely to result from such accidents as a collision or the explosion of a torpedo.

CRUISERS.—So far as general arrangement is concerned the cruiser type of ship does not differ greatly from the battleship, except as regards its superior speed and to some extent its inferior armament and protection. Thus the heaviest guns of the *Minotaur* class cruisers are of 9.2-in. bore, and the main belt has a thickness of 6 in., while the designed power is 27,000 h.p., capable of driving the ship at 23 knots, whereas the designed speed of the *Lord Nelson* battleship is only 18½ knots. There is a strong tendency, however, to make the fighting power of the cruiser more nearly equal to that of the battleship while retaining the high speed, and this has actually been done in the British cruisers of the *Inflexible* and the *Indefatigable* classes. The latter ships have eight 12-in. guns as compared with ten in the case of the *Colossus*, and in addition they have a secondary armament of twenty 4-in. guns. Eight-inch armour is used for the protection of the ships over a considerable portion of their length. A speed of more than 29 knots has been obtained during the steam trials of the *Indefatigable*.

GUN MOUNTINGS.—The larger guns in sets of one, two, or three, are grouped, as already stated, in armoured turrets capable of rotation about a central trunk, through which the ammunition is hoisted from the magazines. In the case of the smaller 6- or 7.5-in. guns separate turrets are not provided, but each gun is enclosed in a casemate which entirely isolates it and the gun crew. In the earlier ships such guns were grouped in an armoured citadel with practically no attempt at isolation, and the explosion of a shell frequently caused widespread destruction, as a result not only of the scattered metal fragments, but also of the spread of the poisonous gases. Under the casemate system the destruction of one gun need not necessarily interfere with the operation of the others.

A section through one of the twin 12-in. gun turrets of H.M.S. *Formidable* is shown in fig. 618, taken from Sir Andrew Noble's work on Artillery and Explosives. There are two 12-in. guns mounted side by side, but upon separate mountings, under the one armoured hood and upon the one turntable, which is carried upon the rollers shown in the illustration. The turntable, together with the guns and their mountings, are therefore capable of rotation relatively to the ship, and this training is effected by means of the hydraulic turning engines marked E in the section. Until recently hydraulic gear has been universally used for the manœuvring

of the heavy gun turrets, but in certain of the recent ships electric motors have been installed for the purpose. The results obtained have not, however, realized all expectations, and hydraulic gear is being fitted to the ships under construction. The working chamber under the gun turntable and the central trunk also rotate with the turret, and through this central trunk is hoisted the ammunition. In the operation of the gun the ammunition is brought by means of overhead carriers from the magazines

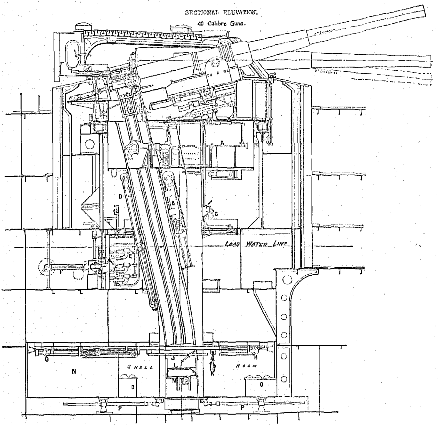


Fig. 618.—Section of 12-in. Gun Turret of H.M.S. *Formidable*

to the foot of the trunk, and is loaded upon the shot tray L, which revolves with the turret. From the tray the ammunition is fed into the carrier of the hydraulic hoist, which transfers it to the working chamber, where it is temporarily stored. When required, the charge is hoisted up to the charging position of the gun, so that when the breech is opened it may be run by means of the hydraulic rammer into the gun chamber. The arrangement of the particular gear illustrated is such that the carrier can only be brought into line with the breech in one position of elevation, but in more recent gun mountings it is possible to charge in any position.

GUNS AND SIGHTS.—The gun itself weighs 49 tons and is carried

upon trunnions, about which it can be elevated through 15 degrees and depressed through 5 degrees. It is also mounted upon inclined slides, and suitable recoil cylinders are provided to absorb the energy of the recoil when the gun is fired. Hydraulic gear is provided for running the gun up the inclined slides into the firing position. For the actual sighting of the gun a telescope with cross wires is provided, and the operation of laying the gun upon the target consists in bringing the object upon the cross wires of the telescope; but it is necessary to adjust the axes of the telescope and gun relatively to one another to obtain the required correction for the range of the target and the deflection. At a small range the axes would be approximately parallel in the vertical plane, but as the distance from the target increases it is necessary to incline the gun upwards by a predetermined amount. This correction is made by inclining the sighting telescope downwards as required relatively to the gun, so that when the cross wires of the telescope are brought upon the target the gun will have the correct elevation corresponding to the range, to the size and temperature of the charge, and to the other factors that determine the amount of the elevation. Upon the gun sight is provided a scale of ranges, and means are provided for applying the temperature and other corrections. Some correction for deflection is also necessary, especially when the target has some motion relatively to the gun. If, for example, in an action the ships engaged were sailing on parallel courses in the same direction and at the same speeds, the gun would be pointed azimuthally directly towards the enemy, that is provided minor errors are neglected; but if, on the other hand, the one ship had a motion relatively to the other, it would be necessary to estimate the relative change of the enemy's position during the very appreciable time taken by the shell in covering the distance. Upon the gun sight there is therefore provided a deflection drum, by means of which the sight may be moved azimuthally to suit the relative speeds. This drum is engraved in knots, and the necessary correction is deduceable from the known speed and course of the ship, and from the estimated speed and course of the enemy. It will be seen from the above that the successful use of a large gun is dependent not only upon the gun crew, but also upon the successful measurement and estimation of various important elements, and for this work numerous ingenious instruments are commonly employed. The distance is determined by means of rangefinders, installed in some elevated position, generally upon special control platforms on the masts, and the range is then transmitted electrically to a central station, from whence, after suitable correction, it is transmitted to the gun positions. An observer in the observation station estimates the speed and course of the enemy, and from the known speed and course of his own ship the necessary deflections required for the various guns are determined. These sight-bar ranges, deflections, and certain orders are signalled electrically to the guns, where they are clearly indicated to the sight setters. The sight setters set the range and deflection drums of the sighting gear to the indicated range and deflection, and thus adjust the axis of the telescope relatively to that of the gun, while the gun layer manœuvres the

gun and gun cradle upon which the sight is mounted, until the cross wires of the sight lie upon the target. Owing to slight errors in the corrections of the various elements of fire, and on account of other minor factors, such as irregularities in the quality of the explosive, variations of temperature, and changes in the density of the atmosphere, it may happen that the shot falls short of or over the target, and a system of fire observation is therefore necessary. From the elevated control platform the fall of each shot is observed, and from the measurements obtained the setting of the gun sights is corrected until the succeeding shots reach the target. With a system of this kind a large percentage of hits is obtainable when one ship alone is engaged, but when several ships are firing, and the target is surrounded by water splashes, the observation of fire becomes a matter of considerable difficulty.

Within recent years one element of uncertainty in the fire of the guns has been very considerably reduced by the installation of refrigerators, which maintain the ammunition in the magazines at a uniform temperature.

TORPEDOES.—Torpedoes form an important part of the armament of battleships and cruisers, and they constitute the main armament of torpedo craft and the sole armament of submarines. They are therefore weapons of great importance, and much attention has recently been expended upon them in increasing their power and speeds to suit the increased speeds of the ships. In ships of earlier date than 1894 the speed of the ship was less than that of the torpedoes, and it was therefore possible with safety to eject them forwards from the bow of the vessel; but as the speed of war vessels increased, the bow torpedo tube was abandoned, owing to the possible danger of the ship overrunning its own torpedo. At the present time the speed of the torpedo has, by a system of heating the compressed air, been made to exceed that of the fastest craft, and it is again possible for a fast destroyer to approach the enemy bow on and fire her torpedo ahead without previously presenting her broadside as a target to the enemy.

In large ships the tubes from which the torpedoes are ejected are submerged beneath the water line, and the actual discharge of the torpedo from the tube is done by means of compressed air. In the Plate the external appearance of one form of torpedo tube and the method of inserting a torpedo are indicated. At the outer end of the tube there is fitted a sluice valve which prevents the untimely entrance of water, and interlocking arrangements are provided to prevent the inner door from being opened until the water in the tube has been discharged and the outer valve closed. The torpedo is then inserted and enclosed, and after the outer valve has been fully opened it is ejected by the admission of compressed air. As the torpedo moves outwards a trigger in the wall of the tube engages with a projection of the torpedo, and thus starts the compressed-air engines. In the conical head, which for purposes of safe storage is detachable, is placed the explosive charge with the contact detonator projecting from the front, and the remaining space is occupied by engines which drive the propellers, compressed-air reservoirs, air-

TORPEDO DISCHARGE TUBE

A torpedo is being inserted by the crew. During the loading operation the exit sluice-valve at the right-hand end, which is built into the skin of the ship, is closed. When the torpedo is inserted and the inner door closed and the sluice-valve is opened, the torpedo is expelled by compressed air. At the moment of discharge a trigger starts the torpedo compressed-air engines, which drive the propeller.

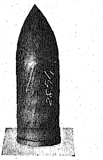
supply heaters, and pendulum or gyrostatic appliances for operating the horizontal and vertical rudders which control the trim and direction of the moving torpedo.

As has been already stated, a remarkable increase of speed has recently been obtained from the simple operation of heating the supply of air before its admission to the cylinders of the engine. In the Whitehead torpedo the air in its passage from the reservoir to the engine is heated in a small steel chamber by means of an oil flame, which is automatically lighted and extinguished when the engine starts or stops. When working with cold air, the power of the 18-in. torpedo is such that a distance of 1000 yd. can be covered at a speed of 35 knots; while, by the addition of the heater, the speed over the same range is increased to 43 knots, and it is now possible to operate at ranges of 3000 or 4000 yd. as compared with the previous working ranges of 1500 to 2000 yd.

As a protection against the attacks of torpedoes, the larger classes of ships are provided with TORPEDO NETS composed of interlinked steel rings. These nets are suspended from the ends of projecting booms, and dip under the surface of the water so as to completely enclose the underwater portions of the ship. In the case of a battleship the nets weigh as much as 80 tons, and are got in and out by the men in three minutes. Mechanical appliances have, however, been installed in the latest ships for performing the work with still greater dispatch. When the torpedo is used against a net-protected ship a ROTARY CUTTER is frequently attached to the nose to enable it to cut its way through the net, and thus reach the vitals of the ship; but the action of these cutters is somewhat uncertain. American and French battleships are not equipped with nets, and from their experience in the late war the Russians have not fitted them to their more recent ships.

ARMOUR.—As a result of the continual contest between the manufacturers of guns and armour, the development of these means of attack and defence has been very rapid, each improvement in the power of the guns being followed by a further improvement in the resistance of armour. In the first protected British ship, the *Warrior*, built in 1859, the thickness of the wrought-iron armour used was $4\frac{1}{2}$ in., and this thickness was capable of resisting the attack of the heaviest guns then made. Until 1874 wrought iron was the best material available, and improvements in the guns could only be met by increasing the thickness, which in the old *Inflexible* of 1874 amounted to a total of 24 in. A portion of the armour, placed only over the vital parts of the ship, was, however, of a compound or steel-faced kind consisting of an outer layer of steel attached by a special process to a backing of wrought iron. In this way a compound plate was obtained having the resistance to penetration of steel and the toughness of wrought iron. As the power of the guns was still further increased it was found necessary to increase the resistance of the plates, and the armour was made throughout of specially treated steel. In armour of the Harveyized kind, introduced in the *Majestic* class of 1894, the steel plates used were cemented upon the outer face, and after being bent to the required form and worked, they were hardened. The process, which is to some extent

typical of later ones, consists in first heating the surface of the plate in contact with carbonaceous material, which cements or combines with the metal to form a surface layer of harder steel. After the work of forming and drilling the plate is completed it is again heated, and the face thereafter douched with cold water until the surface becomes exceedingly hard. Messrs. Krupp, of Essen, in Germany, introduced improved processes, which soon rendered the Harvey system obsolete, and armour of the Krupp cemented (K.C.) and Krupp non-cemented (K.N.C.) types are largely used at the present day. KRUPP ARMOUR is made of high tensile steel alloyed with small quantities of such metals as nickel, chromium, and manganese. Cementation of the surface is carried out as in



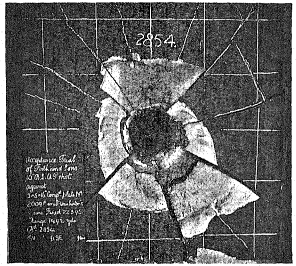


Fig. 619.—16-in. Compound Armour Plate after Penetration by a 10-in. Shell

the Harvey process, but the tempering process differs as regards the reheating of the plate, which takes place from the surface inwards. Non-cemented Krupp armour is only surface tempered, and is therefore of less surface resistance than the former compound type of K.C. As a result of these great improvements it has been possible to reduce the thickness of the plates while increasing their resistance to penetration, and, owing to the great reduction in their weight, the amount of the protection possible in a ship of a given displacement has been correspondingly extended.

Fig. 619 shows a test plate of 16-in. compound armour after penetration by a 10-in. shell, which passed through without breaking up. It will be seen from the illustration that the outer hard layer has been burst off from the backing of tougher material. Fig. 620 shows a 9-in. plate of Krupp non-cemented armour, after being attacked by armour-piercing shell of 13.5 in. diameter, manufactured by Messrs. Thos. Firth & Sons, of Sheffield. As compared with the compound plate, it will be seen from the fracture that the hardness of the plate decreases uniformly from the front surface towards the back.

AMMUNITION.—Until the use of compound armour became general the

makers of ammunition had little difficulty in producing projectiles capable of perforating the uncemented steel plates then in use, but with the introduction of the new armour it became necessary to devise improved projectiles which would not break into fragments on impact. About the year 1886 a suitable projectile, made of chrome steel treated under a special process, was manufactured in France, and on the trial ground it was found that these projectiles could be made to perforate the hard steel face and the tough back of the compound armour and pass completely through without breaking up in the passage. A series of modern armour-piercing shell of this type, manufactured by Messrs. Firth, of Sheffield, is illustrated in fig. 621. It should be remarked that the 13.5-in. shell is the largest that is used at present in the navy,

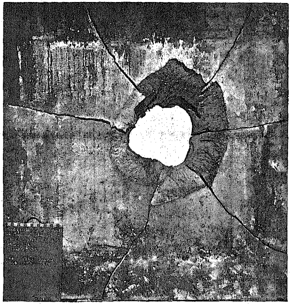


Fig. 620.—9-in. Krupp Non-cemented Armour Plate after Penetration by a 13.5-in. Shell

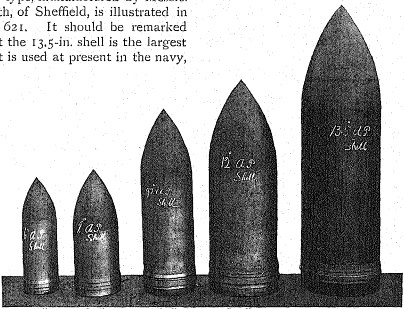


Fig. 621.—Modern Armour-piercing Shells

but 14-in. shells are adopted by some foreign powers. In actual warfare the projectile will in general strike the armour not normally, but at an angle of about 20 or 30 degrees, and under these conditions the difficulty of penetrating the modern all-steel cemented and chilled armour is greatly increased. This difficulty has been overcome to a remarkable extent by the use of soft wrought-iron caps screwed, as shown in figs. 622 and 623, upon the nose of the shell. These caps appear to deaden the shock of the hard steel point of the projectile on the hard surface of the armour, and thus prevent the fracture of the former before the work of penetration is

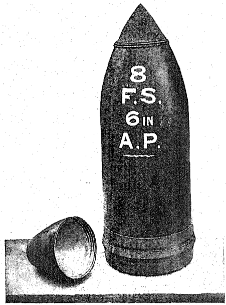


Fig. 622.—Armour-piercing Capped Shell (cap removed)

Fig. 623.—Armour-piercing Capped Shell (cap in position)

commenced; and, in addition, they appear to act as a lubricant for the projectile in its passage through the surface. There is considerable difference of opinion as to the most effective form of charge for armour-piercing shell designed to burst after it has traversed the armour and reached the interior of the ship. When the bursting charge is of high explosive power the shell is broken into innumerable small fragments, the effects of which are widespread but more local than in the case of less active explosives, which break the projectile into a few large parts, each of which may be capable of causing serious destruction. Certain ships, such as the Russian cruiser *Rurik*, have been provided with secondary armoured bulkheads within the hull for the main purpose of localizing the effects of such shells.

EXPLOSIVES.—With the progress of gunnery is closely associated the development of high explosives, but it is remarkable that the most notable improvements were made to satisfy the requirements of civil engineers,

and at the present time the bulk of the explosives manufactured is used in tunnelling, mining, and other peaceful operations. For many centuries ordinary black GUNPOWDER, consisting of approximately equal parts of charcoal, saltpetre, and sulphur, was found to be sufficiently good for military and naval purposes, and until the time of the Crimean war no important changes had been made, except as regards the removal of dust and the production of a cleaner-grained powder. With the introduction of heavier guns it was found necessary to reduce the suddenness of the combustion with a view to reducing the high initial pressures within the gun, which sometimes exceeded 50 tons per square inch. By improvements in the composition and the form of the grains the desired control was obtained, and by the introduction of PRISM POWDER and the still later BROWN PRISM POWDER the initial pressures were reduced to 14 tons per square inch. So far as the purposes of war are concerned, gunpowder has the disadvantage that, since its combustion is not smokeless, the clouds of smoke produced obscure the target, and from about the year 1832 attention was chiefly directed to the production of smokeless powders and more powerful explosives.

In 1832 Braconnet, of Nancy, subjected starch and other materials containing cellulose to the action of concentrated nitric acid, and obtained thereby a very explosive substance which he called XYLOIDINE. This discovery was soon followed by others of a similar kind, and as a result of the work of Pelouze and of Schönbein, between the years 1838 and 1845, the use of GUNCOTTON for mines and torpedo purposes became general. Guncotton is produced by the action of concentrated nitric acid upon cotton, the result being a white friable substance which contains the oxygen required for the combustion of its explosive elements. Owing to its instability and irregularity it was at first found impracticable to use guncotton for any gunnery purposes; but the cause of the instability was shown by an Austrian officer, General Von Lenk, to be due to the presence of free acid, and guncotton of considerable purity was soon produced by Sir Frederick Abel, the chemist of the British War Department. Guncotton and the various guncotton powders at present manufactured have the disadvantages, so far as their use in guns is concerned, that their action is too violent, and that the gases produced contain serious quantities of highly poisonous carbon monoxide.

In 1847 Professor Sobrero succeeded in producing an even more powerful explosive by treating glycerine with nitric acid, but the instability of the compound was such that its use was prohibited in certain countries. After much experimenting, Alfred Nobel, whose name is closely associated with the history of high explosives, overcame the difficulty of handling NITROGLYCERINE by mixing it with about 25 per cent of a highly absorbent natural earth called Kieselguhr, and to the mixture he applied the name DYNAMITE. Kieselguhr is an inert substance which acts as a deterrent, and only serves to weaken and solidify the nitroglycerine, but when used in a gun the solid substance has a serious erosive effect upon the surfaces of the bore. For this and other reasons the use of dynamite is limited to blasting, mines, torpedoes, and similar uses.

As the result of an accident, Nobel, at a later date, made the important discovery that by suitably combining guncotton and nitroglycerine a jelly was formed which could be safely handled, and which was capable of greater control than either of the explosive ingredients. In the composition of guncotton there is an insufficient supply of oxygen for its complete combustion, but, on the other hand, nitroglycerine has an excess of combined oxygen, so that by suitably proportioning the ingredients it

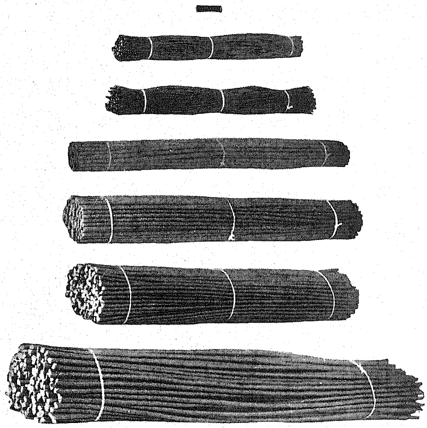
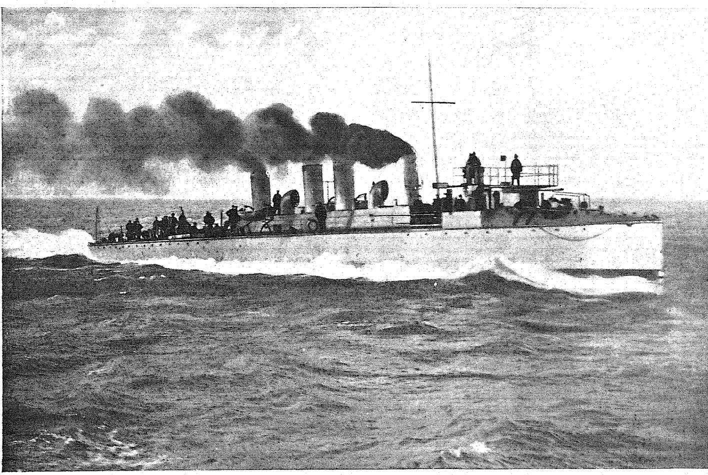


Fig. 624.—Cordite Charges for Various Sizes of Guns

is possible to obtain an explosive which burns without the formation of serious quantities of carbon monoxide or of smoke. BALLISTITE was the first of the many smokeless powders that are now used by all Governments, and in its essentials it resembles the cordite adopted by the British Government. CORDITE consists of 58 parts of nitroglycerine and 37 of guncotton, with 5 parts of vaseline, which assists in lubricating the projectile in its passage through the gun, and, in addition, it reduces the temperature of combustion by nearly 10 per cent. The plastic cordite is moulded by machinery into cords, as shown in fig. 624, and from its final appearance is derived the name. It is found that the combustion of



H.I.J.M. DESTROYER "SAZANAMI"

BUILT BY MESSRS. YARROW AND CO. LIMITED, FOR THE JAPANESE GOVERNMENT

the explosive takes place from the outer surface inwards, and that by increasing the diameter of the cords the intensity of the explosive action can be varied to suit the different sizes of guns. In the combustion of cordite free acid is produced, and the bore of the gun is therefore liable to corrosion unless care is taken to sponge it out after the firing is ended. Messrs. Kynoch have introduced a smokeless powder called AXITE, which does not seriously corrode the barrel of the gun, and which is in other respects superior to cordite. In the illustration (fig. 625) a charge of cordite and a similar charge of the new explosive are shown, and from this illustration it will be seen that the axite is formed of ribbed strips having a considerable surface. As compared with cordite, a greatly increased muzzle velocity is obtainable without an increase of pressure, and it is claimed that the effect of atmospheric temperature on the pressure and velocity of the gases is only one-half what it is with cordite.

Picric acid, which is now extensively used in large shells and projectiles, was for some years employed as a canary-yellow dye until its dangerous properties became evident. In this country the picric acid manufactured is known as LYDDITE, while the equivalent French explosive is called MELINITE. The Japanese manufacture a special form of picric acid which they call SHIMOSE, and in the recent war after each engagement the Russian ships were splashed with the strong yellow colour characteristic of picric acid.

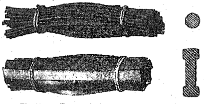


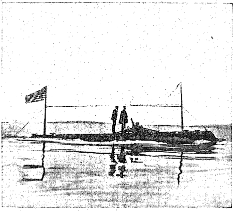
Fig. 625.—Comparison of Cordite and Axite

TORPEDO CRAFT.—The introduction of the torpedo boat over twenty-five years ago has resulted in the development of other types of torpedo craft of sufficient speed and strength to overtake and destroy the former. To counteract the attacks of torpedo boats a larger type of vessel armed with light guns of 4.7-in. and smaller calibres was developed, but as the size and weight of these torpedo gunboats was gradually increased it was found necessary to introduce a specially light and speedy type of torpedo-boat destroyers, armed with guns of sufficient power to inflict serious damage upon the torpedo boats. Thus the *Dryad* class of torpedo gunboats, built in 1893, had a displacement of over 1000 tons and a speed of 17 knots, and were armed with two 4.7-in. guns and five 6-pounders. The first torpedo-boat destroyers, built in 1893–4 by Messrs. Yarrow and Messrs. Thornycroft, had a displacement of only about 250 tons, but owing to the adoption of water-tube boilers it was possible to obtain a speed of over 27 knots. The armament consisted of one 12-pounder and three 6-pounders in addition to one torpedo tube. These early craft were found to be excellent sea-going boats and to be well suited to the purpose for which they were designed, but in later vessels the speeds were gradually increased to 30 knots. It was found, however, that the efficiency of the vessels was seriously affected by bad weather, and in 1902 the British Government decided to adopt in their new destroyers a lower maximum speed of $25\frac{1}{2}$ knots. These vessels, known as the River Class, have a

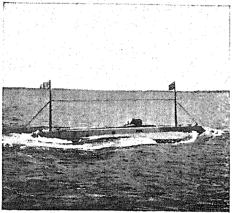
displacement of 525 tons and have proved to be very serviceable in the open sea; but owing to their high freeboards and raised forecastles they present a considerable target. Within more recent years a further change of policy was effected, and the torpedo destroyers provided under the estimates of 1907–8 have a speed of 33 knots. Their displacements of from 800 to 1000 tons ensure a large radius of action with good sea-going qualities, and vessels of this type are described as "ocean-going" destroyers. As a result of experiments with the *Albatross* and *Express* it was considered advisable to adopt turbine machinery, and the remarkable continuous speeds of over 35 knots that have been obtained with certain of these destroyers is due to the use of turbines and to the adoption of oil fuel for the automatic firing of the water-tube boilers. This high speed appears however to have been attained at too great a cost, and there is a tendency in the latest destroyers to revert to more moderate speeds of 27 knots and powers of about 13,000 h.p. In the Plate is illustrated the destroyer *Sazanami*, built by Messrs. Yarrow & Co., Ltd., of Scotstoun, Glasgow, for the Imperial Japanese Navy. On the trials a speed of 31 knots was maintained. The horse-power of the engines is 6000, and the displacement is 306 tons.

SUBMARINES.—Since the year 1901 the construction of submarine vessels has been actively undertaken by all the greater naval powers, but the practical introduction of such boats may be considered as dating from 1888, when the French Government built the *Gymnote*, which was followed in 1893 by the *Gustave Zédé*. The former had a displacement of only 36 tons, with a surface speed of 6 knots and a submerged speed of 4 knots, while the latter had a displacement of 260 tons with a surface speed of 10 knots, and a submerged speed of 5 knots. Surface speeds of at least 15 knots are now considered necessary to enable such vessels to approach within striking distance of a battleship fleet, but the weight of the machinery required for the higher speeds and the desire for greater torpedo-carrying capacity has led to a considerable increase in the size of submarines. British boats of 800 tons submerged displacement are being built. Their surface speed is 15 knots, and when submerged about 9 knots. The highest possible surface speed is provided to enable the submarine to take up a suitable position before the enemy, preparatory to sinking beneath the surface of the water for the purpose of approaching within torpedo striking distance, and the high speed ensures some chance of escape after an attack. When slightly submerged the direction of the boat is to some extent made possible by the use of a periscope, which projects upwards through the surface of the water; but when the boat is more deeply submerged the range of periscopic vision is very restricted, and more especially so when the waves are high. In actual service, therefore, a submarine when submerged can only be run blindly, and the officer in charge is dependent for his direction upon the observations made when running near the surface, and upon the indications of the compass placed well above the hull in the observation hood.

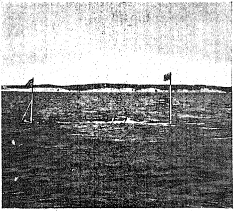
Vessels capable of operating when completely submerged are generally known as submarines or as submersibles, but the distinction is in no



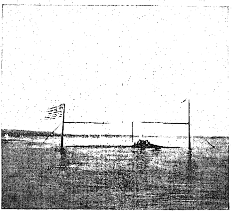
RUNNING ON SURFACE



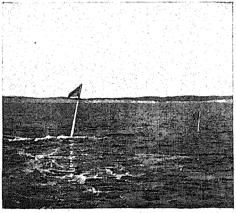
FULL SPEED ON SURFACE



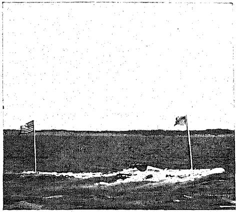
RUNNING AWASH



TRIMMING TO DIVE



DIVING



COMING TO SURFACE

THE HOLLAND SUBMARINE BOAT

UNDER VARIOUS RUNNING CONDITIONS

Length overall, 63 ft. 4 in.; Beam, 11 ft. 9 in.; Submerged Displacement, 120 tons. Propelled on the surface by [illegible]

way definite. In general, however, the SUBMERSIBLE is a vessel capable of sinking directly downwards upon an even keel, instead of diving at a small angle while running forward; and it is this submersible type that has been adopted and brought to a high degree of efficiency by the Italian Government. In these boats the submergence is effected by means of vertical screws disposed within tubes passing from the bottom to the top of

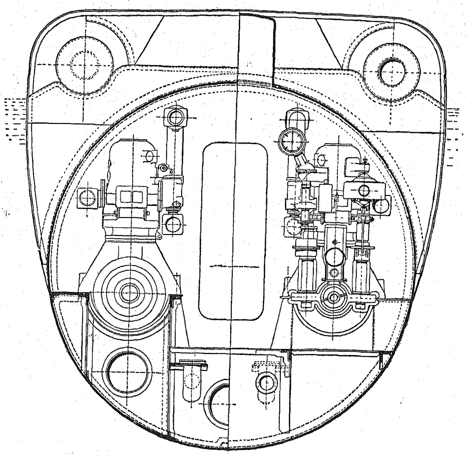


Fig. 626.—Cross Section through Engine Room of Submarine (from *The Engineer*)

the hull. In the case of the ordinary submarine the trim and buoyancy of the vessel are first slightly altered by the admission of water to certain of the compartments, and the vessel then dives forward under the surface of the water at an angle determined by the inclination of the horizontal rudders. Several views of a Holland submarine boat are given in the Plate, which illustrates the various conditions under which these craft operate.

The depth at which a submarine may be expected to run will not in general exceed 60 to 80 ft., but the hulls of such vessels are designed to safely stand the pressure of 150 to 200 ft. of water, and submerged tests are frequently carried out at depths of 150 ft. with the

crews on board. To withstand these pressures a circular section is commonly used, as shown in the transverse section through the engine room of one of the latest Russian boats, fig. 626; but other suitably strengthened forms, which permit of a better arrangement of the machinery, and which give better sea-going qualities, are sometimes used. The section shows the arrangement of the superstructure with the oil-fuel tanks arranged for safety entirely outside the hull, and fig. 627 is an illustration of the boat, the *Kambala*, steaming at full speed 11 knots upon the surface.

Engines of an internal-combustion type are used for the propulsion of submarines on the surface, as the greatest power can thus be obtained at the smallest expenditure of space and weight; but oil and vapour engines consume large quantities of air and produce hot and objectionable waste gases, and it is therefore impracticable to use the main engines when submerged. At the present time the main engines are employed when

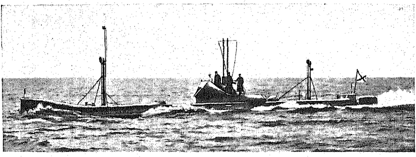


Fig. 627.—The Imperial Russian Submarine *Kambala* steaming at 11 knots

running upon the surface, not only for propelling the vessel, but also for charging electric accumulators, and when the vessel is submerged the propeller shafts are driven by motors supplied with current from the charged accumulators. Certain dangers are involved in the use of accumulators which contain dilute sulphuric acid, and serious accidents have resulted from the evolution of quantities of chlorine gas, due to the accidental entrance of salt water to the accumulator spaces.

In the most recent vessels special care has been taken to ensure safety, by dividing the hull into water-tight compartments and by sealing up the accumulator cells, so as to prevent the entrance of salt water; but care is at the same time taken to efficiently ventilate the cells, as disastrous explosions have resulted from the accumulation of the gases produced under normal conditions of working. Owing to these and other dangerous features, such as the use of explosive vapours, the small margin of buoyancy, the blindness of the vessel when running submerged, and the danger of reaching low levels at which the pressure is sufficiently great to cause either serious leakage or the collapse of the hull, the possibility of disaster is still present to a large extent; but during the few years that have elapsed since the practical introduction of this type of vessel great progress has been made in eliminating the many dangers which attend the use of these vessels, even in times of peace.

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